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Mobile Technologies for Improved Collaboration on Construction Sites

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1 Abstract

There has been increased efforts in the introduction of Information and Communication technologies (ICT) in construction to support collaboration. However there is still little focus on support for mobile users on construction sites. It can be argued that it is often on the construction site that ICT tools can offer the greatest benefits as they can enable the timely collection of information and knowledge during the build process.

Convergence in networks, the merging of voice, video and data provides increased opportunities for mobile workers, allowing for a greater array of information to be shared to support collaboration on site. This paper looks at convergence, as well as other technologies including mobile computing, speech recognition and the use of multimedia content to support the construction worker on site and ensure a smooth decision making process.

The paper describes several construction case studies, including the Heathrow Terminal 5 project, where decision making processes were examined, along with ICT usage. A scenario illustrating the use of advanced ICT on site was developed to gather requirements for a technical solution which could support the decision making process, and ultimately collaboration during construction.

Requirements for an ICT support system were defined with the use of the case studies and scenario analysis, the proposed solution which combines many of the latest advances in ICT in a single system is then presented. It is explained and demonstrated that this could support the decision making process by allowing more information to be accessed and shared from the construction site. The use of advanced communication technologies such as convergence and Voice over Internet Protocol (VoIP) can ensure that audio information can be retrieved along with other project data to provide a clearer more fluid decision making process where all relevant project members can easily be up to date with project progress.

Keywords: Convergence, Mobile technology, Collaboration, Construction, ICT

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2 Introduction

It is often ineffective communication practices along with organisational fragmentation and the lack of integration between design and production processes that lead to poor performance in the construction industry. Research revealed that despite the extensive planning that takes place on any construction project, it is often the case that when work begins on the construction site, unexpected problems arise which call for immediate attention (Dainty et al., 2006). Companies usually have processes in place to ensure the logging of changes and the appropriate dissemination of information; however the reality is that many changes go undocumented.

Collaboration tools have been introduced within construction projects to support the flow of information between project members. These partners often reside in different locations from design offices to construction sites where the flow of information is essential in supporting ongoing construction tasks but access is usually restricted to the site office. It can be argued that the timely collection and dissemination of information to project teams would help reduce and resolve the number of unexpected problems highlighted by Dainty et al., (2006).

Mobile technologies have been identified as important components within the overall ICT support for construction sites, important issues to consider being: communication infrastructures, appropriate software and tools, adequate training, and the management of implementation. Research into this area investigated the use of tablet PCs (Ward et al., 2004; Lofgren, 2007), personal digital assistants, and pocket computers (Bowden et al., 2005; Niemi, 2007; Kimoto et al., 2005), and the testing of various communication links including wireless networks (WLAN) (De La Garza et al., 1998; Ward et al., 2004; Brilakis, 2007). Research into the WLAN has found it to benefit the flow of information on site and to facilitate certain processes such as the request for information from design teams. With more WLAN standards being released offering greater reliability and bandwidth, the benefits of wireless networks are still to reach full potential. Research into the use of PDAs has found them to be useful given the correct application, but Issues have been raised regarding their durability and functionality (Kimoto et al., 2005; Niemi, 2007). Furthermore, the use of collaboration environments such as project extranets can facilitate communication and the sharing of information between project partners using different hardware and software, however little of the data collected on site is managed efficiently and so remains unusable.

Another important advancement in ICT is the emergence of convergence in networks and communication, this is enabling the merging of voice, video and other types of data in a single system. Converged networks are being used within various industries to incorporate voice into mainstream data networks using Voice over Internet Protocol (VoIP) bringing cost savings by having a unified infrastructure and integrated data systems. These are all applicable to and can benefit the construction industry as reported in Ahsan et al. (2005) and Beyh et al. (2006).

The advantage of convergence is in the ability to mix different applications together, for example Aston University installed a converged network which allowed for all communications to be carried over the unified network. This network allowed for the university to broadcast their own TV service, as well as give access to room schedules via the telephone system (Improcom, 2005).

Converged networks can also be used with mobile devices enabling access to communication services such as video and voice, as well as access to project information on a single device, when on the move. Therefore convergence in communication have the potential of improving and facilitating collaboration on construction sites. The possibilities include the use of live video conferencing using PDAs and tablet PCs while accessing real-time data for the monitoring of site processes.

This research is looking at how convergence can support collaboration using mobile computing to help resolve some of the problems encountered by site personnel during construction. The research presents a scenario detailing the potential use of a converged infrastructure with the aim of defining the requirements for an advanced multimedia communication suite for the construction site worker to collaborate with other remote workers. The validation of the scenario took place at various construction sites with project managers and design engineers. A review of the change processes on projects was undertaken and feedback on the use of the new technologies were collected. This information allowed for a set of requirements to be collated for the development of a technology solution for future deployment and testing.

3 Mobile Technologies in Construction

Mobile technologies have been the attention of increased research investigating their use in construction. According to Moore's law stating that every two years the power of chips will double without affecting chip size (Moore, 1965), this is now making it possible for applications traditionally restricted to the desktop computers to be used on the mobile device. It has been shown that PDAs and tablet PCs can be used as effective data collection and communication devices (Bowden et al., 2005; Ward et al., 2005). The PDA has also been used with attachments such as barcode readers to support the management of materials supply and storage on site (Tserng et al., 2005). Another useful application of the mobile device within construction is the fast and efficient remote access to information from the construction site for decision making.

Figure 1 shows the main components of mobile computing: the hardware, the network and the services (Cus-babic et al., 2003).

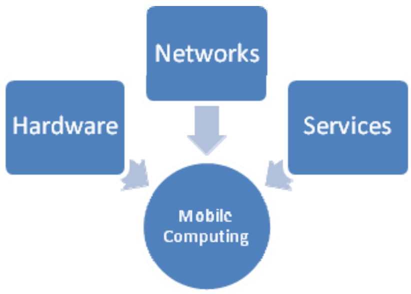

Figure 1 Components of Mobile Computing (adapted from Cus-babic et al., 2003)

3.1 Hardware

Research into the communication hardware used within construction reported that the mobile phone is the key tool used on site for voice communications (Ahsan et al., 2005, Howard and Petersen, 2001). The GSM network, which is the standard for all operators within the UK, has a 99.9% coverage (02, Vodaphone, and Orange Networks)(GSM World web site), enabling the majority of construction sites to have real time communications. However, access to the network is costly, and although the technology is improving to allow faster bandwidth, the cost of data access is still high. Research also identified short messaging services (SMS) as a quick way to send messages and alerts, and can be used effectively when coupled with a larger monitoring system (Lu et al., 2006).

The desktop computer or laptop is the common device used in the site office giving access to email and other systems to enable communication with the rest of the project team. A variety of other devices have also been being tested, tablet PCs were used for information management and showed that improvements can be achieved by increasing issue resolution speed, reducing rework, allowing crews to maintain productivity, and ensuring that construction quality standards were maintained (Lofgren, 2007; Ward et al., 2003). There were however several shortcomings of using tablet PC's on site, these were found to be portability due to the size of the tablet PC, and cost, with the improved rugged versions for impact resistance costing about three times more than a standard device.

Research into the PDAs found established the following requirements (Bowden et al., 2002):

- Portability – the size of the device will affect its portability
- Display – larger colour screens take up more power than simple monochrome.
- Batteries – the need for longevity on site.
- Expansion – the ability to enhance the device with a digital camera, bar-code reader etc.
- Ruggedness - The device should be durable for the construction environment.

Tests with the PDA in real estate management found them to be of better than the tablet pc as it allowed for greater mobility due to the small size which enabled it to be taken to small confined spaces. The PDA device is also small enough to fit into a pocket allowing for hands free use, however, improvements in data entry were recommended for PDAs due to restrictions on peripherals such as keyboards (Niemi, 2007).

The type of applications being run by the device have an impact on the functionality when on site. Running CPU intensive applications can hinder the use of the PDA due to its limited CPU size, and heavy usage of the wireless network would have adverse effects on the battery life. Although the CPU size is increasing for PDAs and battery life is also on the rise, they are still not adequate for high demanding applications such as video conferencing (Johanson and Torlind, 2004), although tests have shown that it is suitable for basic data entry (Kimoto et al., 2005). It is important to note that research on battery life was carried out in 2005, and the technology has since undergone several cycles of improvement.

The Smartphone/PDA Phone, which is a cross between a mobile phone and a standard PDA can be used as a suitable device for the industry. It allows the user to switch between the standard GSM and corporate networks depending on availability. This can ensure that site staff are always connected and given access to the advantages offered by convergence. Although the majority of the research on the Smart phone exists in domains other than construction, the same applications can be used on a standard PDA offering the same functionalities. Research into these types of devices have highlighted several uses including remote fault monitoring, with the facility to automatically call or alert designated individuals if the sensors recognise abnormal machine status (Wanbin et al., 2007) and also the use of the camera on the device for text recognition to speed up data entry (Siegemund et al, 2007).

3.2 Networks

Networks are an essential component for mobile computing as the hardware infrastructure usually defines the applications and functions that can be used depending on the bandwidth and cost. A data network is essential to offer the site staff access to email, now an essential communication media in construction (Ahsan et al., 2005), together with the internet for access to project collaboration tools.

Deployment of a network on the construction site can be an arduous task due to the many complexities of the outdoor environment and the constantly changing landscape, wireless networks currently presenting the best solution

Various different wireless infrastructures have been explored with the aim of enabling data flow around the construction site. The Construction Site Mobile Operations Support (COSMOS) (Meissener et al., 2002) and Mobile Integrated Communication in Construction (MICC) (Deguine et al., 1999) projects tested various technologies on the construction site including DECT (Digital Enhanced Cordless Telecommunications), GSM (Global System for Mobile communications), WLAN (Wireless LAN), and TETRA (Terrestrial Trunked Radio). The MICC project showed that the DECT technology is suitable for the construction sector because of its reliability (Deguine et al., 1999) but has interoperability problems and cannot match the bandwidth of other technologies such as the WLAN, therefore running both data and voice intensive applications would prove difficult.

The WLAN in the form of the IEEE 802.11 standards (http://standards.ieee.org/getieee802/portfolio.html) provide a relatively simple way of extending the data network from the site office into the construction site. The various benefits of the wireless network on site has been highlighted by many researchers (Bowden et al., 2005, Ward et al., 2004, Brilakis, 2007), which include access to read and update project information.

The wireless network can be deployed in various topologies offering a mix of bandwidth and range. However, when it comes to deploying on the construction site, there are various to be overcome such as the availability of power and the exposure of the hardware to the elements. Tested solutions include the use of weatherproof casing for the hardware and using power from machinery and vehicles (Ward et al., 2004, Brilakis, 2007). This can provide the added advantage of having mobile access points which can allow for rearranging of the network for maximum performance.

Kuladinithi et al., (2004) presented an ad-hoc wireless framework for on-site communication; however it was found to be limited in both bandwidth and range. The ad-hoc solution used all wireless devices available to send signals back and forth. A similar principle is used in the wireless mesh network known as Wi-MESH. In theory this could be a good solution for the construction environment as it promises greater reliability (with no single point of failure) and simplicity in deployment and maintenance leading to fewer upfront costs (Akyildiz et al., 2005). The technology allows each access point to act as a router with several available paths to a desired destination and can be applied to highly changing environments (Hiertz et al., 2006). Research into the Wi-MESH network however found that there are still limitations to the standard that prevent it from reaching its theoretical capacity (Akyildiz et al., 2005, Hiertz et al., 2006).

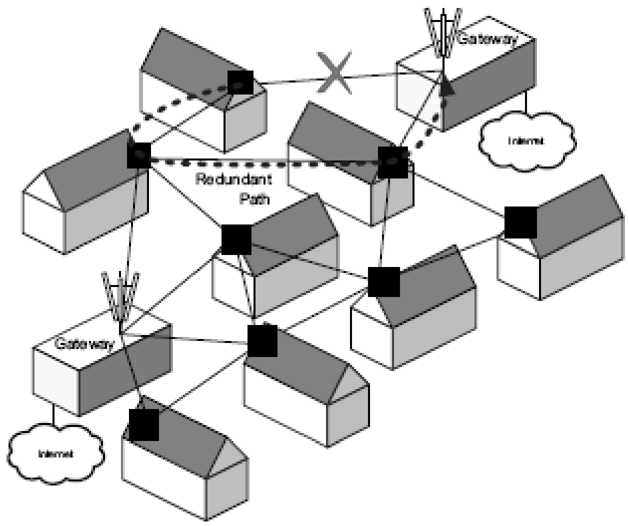

Figure 2 Wireless Mesh Network (Hiertz et al., 2006)

Worldwide Interoperability for Microwave Access (Wi-Max) is another standard within the wireless 802.11 family which can be used within the construction context to offer internet access to remote sites. The standard allows for high speeds of around 35-135 Mbps and a range of up to 70-80km (Kuran and Tugca, 2007). Although Wi-Max has not been tested construction sites, outdoor tests have found it suitable for high bandwidth usage such as voice (Agapiou, et al., 2006). The disadvantages of Wi-Max include the cost of hardware, and the lack of a fully tested standard. Currently there exist vendor implementations that lack of interoperability between the technologies provided by different manufacturers. The use of this type of infrastructure would be to provide the backend connection, connecting the construction site to the internet, and would be extremely useful on remote sites where access to telephone networks is restricted. Other wireless standards are available for connecting construction sites to the internet and offer a variety of speeds and ranges, with very fast networks capable of giving a few gigabit's of bandwidth, however, they come at a high cost (Kuran and Tugca, 2007). Other methods of connecting a remote site to the internet include the use of bridges placed at certain distances to allow signals to be sent to the site. The testing of this method (on a university campus) found that common wireless ready devices could connect and transfer data to a central computer provided the minimal signal strength was met (Brilakis, 2007).

3.3 Services

Services are the applications and tools available on mobile devices, with the power available for mobile devices increasing, applications traditionally restricted to desktop computers can now be used on hand-held devices. The applications however tend to be smaller and less functional than their desktop counterparts due to the lack of CPU power. Services available to mobile devices generally support communication, whether between applications or project members. Seven facets of communication within a project which take into account the various types of communication within a project (Anumba et al., 1997) are:

1. Communication between intra-disciplinary CAE (computer aided engineering) tools.
2. Communication between each project team member and their design tools.
3. Communication between design team members.
4. Communication between each discipline and the common project model
5. Communication across the stages in the project life-cycle.
6. Communication between the project team and third parties.
7. Communication between inter-disciplinary CAE tools

These seven facets summarise the various types of communication taking place within a project and can be aligned with the various services offered by mobile computing. Investigating the applications themselves, Chen and Kamara (2006) simplify the facets of communication in line with mobile computing into three main categories:

1. Mobile CAD applications – Chen and Kamara (2006) identify several products which can be used on the mobile to view and modify CAD drawings, however they note that in order to link the data to a PC, the mobile device must be synched by plugging it into the computer.
2. Data Capture applications
3. Project Management applications.

Communication tools can be included in the third category and are further details in the sections below.

3.3.1 Advanced communication on site

Convergence can impact on many activities on and off site, in all phases of the construction lifecycle, but for the research carried out, the area of communication on site is investigated, with several technologies such as voice over IP, video conferencing and speech recognition playing an important role.

3.3.1.1 Voice over IP (VoIP)

IP telephony which was first introduced in the 90's enables voice packets to travel on the same infrastructure as other types of data bringing about some interesting possibilities for collaborative working.

- Research examining the adoption of VoIP within the construction context has identified several issues which require further research (Ahsan et al., 2005; Beyh and Kagioglue, 2006):the nature of information to be transmitted such as voice, video, and other types of data
- Data access by various project teams
- Reliability, availability and quality of service

- Cost of service including network administration, maintenance and upgrade
- Availability of terminals and users' devices such as mobile handsets.

When examining the technical issues of introducing the technology, it was established that many of the barriers such as reliability and security can be overcome by adopting tried and tested techniques to solve similar problems adopted by other sectors such as manufacturing and IT(Ahsan et al., 2005). The adoption of VoIP within construction could then be used to support communication between employees. A fundamental benefit of VoIP for the construction industry is in the savings on communication costs. A survey of the construction industry found that at present it spends on average between one half to a million pounds every year on voice communication (Ahsan et al., 2006). A large portion of these costs are related to mobile telephony, it is believed that by using a WLAN on the construction site and tunnelling calls through the internet cut these costs as well as providing greater control over reporting. Implementing a WLAN would require the use of faster network standards such as 802.11g (capable of 54mbs), research showed that using 802.11b (capable of 11mbs), the data would make many hops from one access point to another and the voice quality would degrade (Keppes, 2005). The switch over to VoIP would therefore require most businesses to reassess their network capabilities and invest in better network infrastructures. Another important advantage of VoIP is that communications can be uniform across the different construction sites and head office, allowing the same contact details to be used from one site to another.

3.3.1.2 Video Conferencing

Video conferencing can be seen as an extension to VoIP, as the same underlying technology and infrastructure is used to establish a connection and transmit data. Work carried out by Johanson and Torlind (2004) showed that it is possible to use video conferencing on a mobile device, however the devices tested lacked the power to provide a reliable service. They also raised concerns about the ability of a standard wireless network to manage a call when a user is mobile and moving from one access point to another. Wi-MESH networking is a possible solution to the problems of handover and the reliability as multiple access points are used to form a robust network; however the Wi-MESH network is still not well established because the associated 802.16 standard is not fully developed yet (Hiertz et al., 2006).

3.3.1.3 Speech Recognition

One of the issues faced on the construction site is the best method of entering data when on the move which can be dependent on the device used. The tablet pc is adequate for data entry by both handwriting and use of a virtual keyboard. Niemi (2007) noted that this type of data entry is difficult when using a PDA and adopted audio recordings as an alternative. Research in the medical field trialled voice recognition for data entry with mixed results. A successful test achieved word recognition rates of around 98% using desktop based speech recognition engines but required a domain specific dictionary to be created (Happe et al., 2003).

Voice can also be used as an interface to control machinery, this was demonstrated in a test to control simple functions for a robot, the instructions being sent via a PDA over a wireless network to a centralised speech recognition engine that sends the instructions to the machine (Ayres and Nolan, 2006). Although only simple commands such as forward and back were achieved, it does show some interesting possibilities to be explored within the construction context.

Research has also examined the use of voice as an interface for applications such as databases and websites using VoiceXML. A prototype multimodal interface browser and VoIP phone was developed enabling users to combine internet and voice where the information about the person being called can be displayed at the same time as interacting with them vocally (Tsai, 2006). Applying this on the construction site could allow workers to gain access to information using hands free voice control.

4 Research Methodology

The research was based on the general hypothesis that the converged network along with mobile computing could be used on a construction site to support mobile collaboration and thus reduce the time taken for information requests to be logged and corrected. Information gathered from earlier research (Ahsan et al., 2005, 2006), along with a literature review and consultations with technology experts was used to generate a framework illustrated with the use of a scenario. The scenario showed how various communication technologies could be used by a mobile construction worker. The scenario was then presented to members of the industry to formulate a plausible use of the technology and gather a set of requirements for tools that can be put to use today.

The scenario focused on the issue of handling changes or problems which arise on site requiring input from the project team in order to decide on a path forward. It was established that the resolution of these problems on site are costing the construction industry in the region of £2 billion a year (BRE,2005).

The definition for a scenario used for the purpose of this research is "a story that one person (or group of people) can tell another, and that describes human work, human collaboration, or human activity (with or without computers)" (Muller, 1999). Muller (1999) has identified several uses for scenarios:

1. Analysis of human work and collaboration with a balance between a focus on technology and a focus on human processes
2. Consumer engagement
3. Design and implementation of systems
4. Usage-guided testing of systems

For the purpose of this research, the aim of using the scenario was the design and implementation of a system. The scenario was used to show how a multimedia communications suite would be used onsite. The multimedia communications suite would show how the different technologies can be used practically on site to support the flow of information and communication. Leading VoIP technology experts (ATC Communications, SpinVox) were also consulted in order to identify a suitable deployment strategy for the construction site.

The scenario method used for the research was a combination of collaborative design workshops and mock-ups. The collaborative design workshop uses a task sequence to discuss work practices, variations and alternatives, whilst the mock-up method uses a mock-up of either coarse granularity (e.g. Cardboard boxes for computers) or fine granularity (e.g. Detailed screen images) to walk through contextualised work scenarios (Muller 1999).

A flowchart showing the process of change using the new technologies was produced (see fig 3). The basic process was taken from the 'Code of Practice for Project Management for Construction and Development' published by the Chartered Institute of Building, and then expanded to show the technology being used. The basis being to explore situations based in the construction workflow where the technology could support and enhance the work activity.

For the mock-ups it was chosen to go with fine granularity with detailed screen-shots created to show an example of the technology in use. The screen-shots were not a final specification of the user interface, but were used to help support the scenario and gather a greater feedback of greater detail. Figure 4 shows samples of screen-shots used, where the presentation also included samples of the desktop interface used by the architect in the scenario.

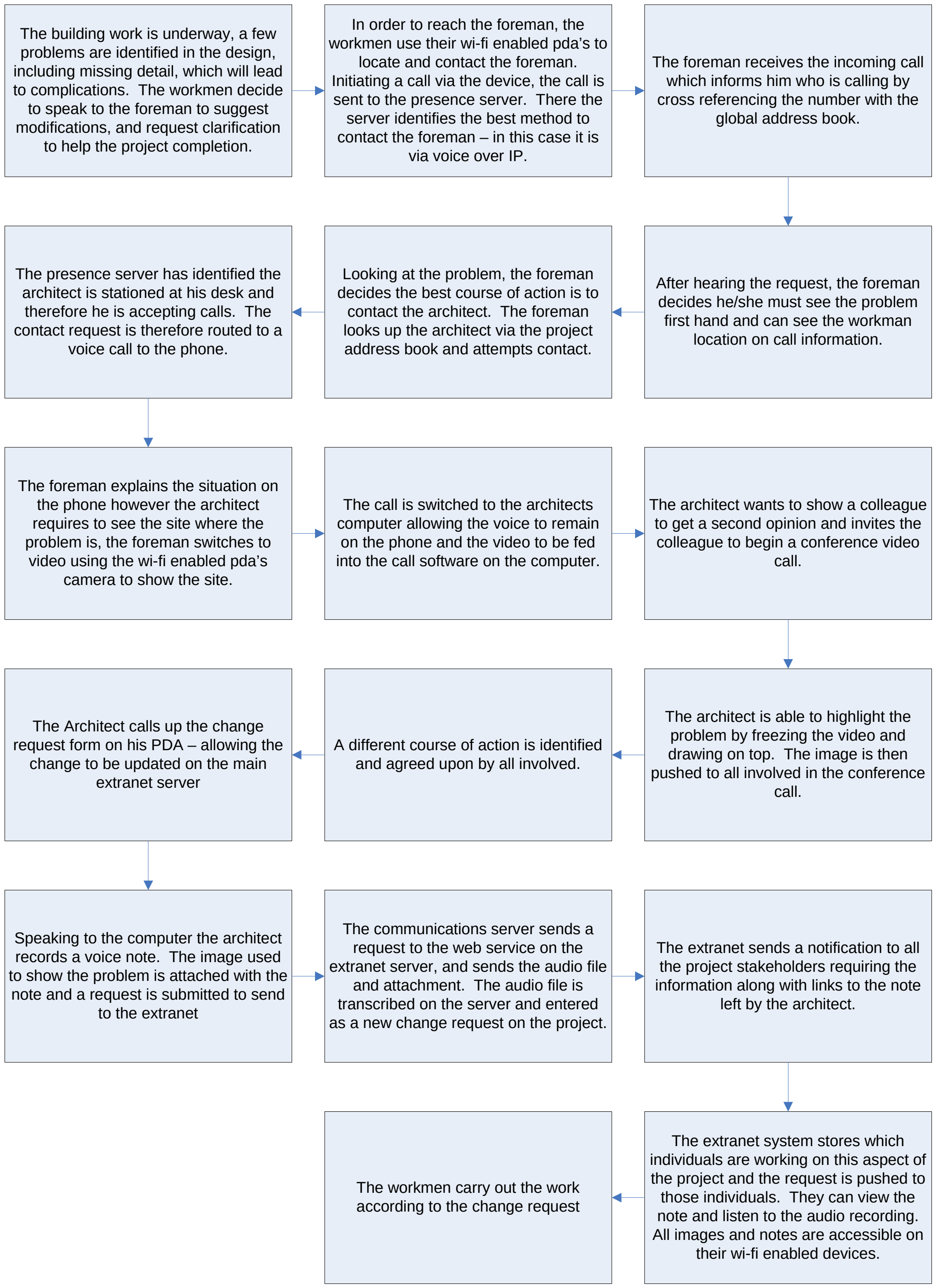

Figure 3 Process chart used in the scenario

To validate and refine the scenario, consultations were conducted with project workers at three construction sites of various sizes and stages. The three companies used to validate the research were Amec, one of the principle contractors at the Heathrow Terminal 5 (T5) extension; Costain which is delivering rail infrastructure to support a large retail development in London; and Laing O'Rourke which is developing a new student accommodation complex at Loughborough University.

On the sites where work had begun (Amec and Costain), the work in progress was examined and current IT usage evaluated. The scenario was presented to the project managers to evaluate how mobile computing could help support their change management processes.

Figure 4 Mock-up screen shots used in the scenario process

5 Case Studies

5.1.1 Current IT infrastructure

All three companies had access to the internet at their site offices. Both Amec and Laing O'Rourke had IT infrastructure provided for by the client, whereas Costain had to setup their own. All site offices were fitted with networks and computers to allow site staff access to the internet and email. All three companies used email as the standard for communication and collaboration, as it allowed an audit trail to be kept, and was simple to use.

Costain had implemented a document management system which managed project documentation as well as emails. The system was web based and allowed users to track emails to ensure recipients had read and acted on set tasks. All project stakeholders had access to the system including the supply chain and the client. Costain require members of the project team to use the system to enable them to manage the project effectively, which is different to findings of Brewer (2006) who noted that firms in Australia were reluctant to force other project partners to adopt an IT system as it could lead them to have increased costs and reduce the number of project partners.

Laing O'Rourke had a document management system for their drawings called Asite. This was a web-based system allowing project members to share drawings. It was noted that video conferencing was used at the head offices of Laing O'Rourke however this was not implemented at any of the site offices.

Wireless networks were not deployed on any of the sites, however some machinery on the T5 Heathrow site used radio frequency to transmit data, forming an 'ad-hoc' network. For example the concrete laying system created by Leica Geosystems had a control system which communicated with total stations in order to accurately position the concrete-laying machinery. The total stations positioned on the ground would communicate with a computer onboard the concrete laying machine wirelessly, with position information being transmitted 6 to 8 times a second (www.leica-geosystems.com). Amec had problems with the machinery, which was believed to be causing interference within wireless communication and resulted in Amec having to carry out an RF (Radio Frequency) survey to identify possible sources. The survey uncovered that some RF devices were being used in the till machines at a nearby canteen servicing the site to transmit stock information. Although ultimately this was not the cause of the problem (which was due to a program error), it does show the importance of running a survey and constantly evaluating the airwaves to ensure optimal performance of a WLAN.

5.1.2 Current Processes

The research confirmed that on all sites, changes were being requested which required communication with the project team. The process of handling the change differed between the three companies.

When evaluating the processes shown in the scenario, it was clear that the foreman would not be involved in the decision making, and hence replacing the foreman in the scenario with the site engineer would ensure a more accurate process.

The T5 Heathrow project use a process termed a 'rolling design', which meant that the design was constantly changing. Depending on the change requested, the process would involve the site engineer collaborating with the design team to work out a solution. This could involve the site engineer creating a new CAD drawing to show the solution, but often a simple sketch was used. The final design would be left for the design team to update on the project server. There can often be delays in getting the updates included in the working design, which was identified as the root for a few delays on site. Documentation includes a non-conformance report which is created if there is a substantial change, however the documentation is usually left to a later time when the engineer has access to the computer. The time duration for the change to be 'processed' would vary depending on the scale, however it could range from an hour to a couple of days.

Costain had a similar approach to Amec, with the site engineer and the designer being involved in the decision-making process. The mobile phone was often used to discuss changes, and small changes would be agreed over the phone, with a follow up email to confirm the decision. The email would often be sent after the change was put in place, as the site engineer would be required to go to the site office to create the email. With Costain using a document management system, the email would give a clear audit trail and the details of the change would be available to all project stakeholders. If the change had an impact on others close to the site, then a third party agreement would have to be signed, which could cause the decision to take as long as two weeks to be finalised.

Laing O'Rourke identified the project manager as the central broker for the flow of information. All requests would go through the project manager who would be involved in the decision-making process. The project manager would then identify the best course of action, and decide on which members of the team would be required (figure 5). If the change was major, an instruction request would be sent to the client for review, with changes taking on average 2-4 weeks to be signed off.

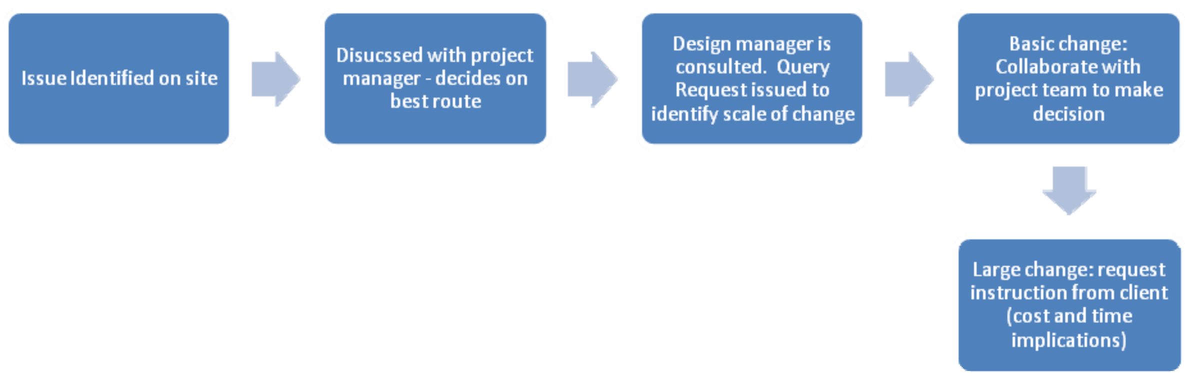

Figure 5 Change process used in Laing O'Rourke

5.1.3 Problems identified

An important problem raised at the T5 Heathrow site was the slow update of drawings after changes which was partly the result of the rolling design process. However, delays in logging new information was common on all the sites. Even with management systems in place, the research found that updating and completing the documentation was dependent on the engineer having the time to go to the office and performing the tasks manually.

The scenario highlighted how instant communication with team members would help support the site worker, and how decisions and changes could be logged as and when they occur. This would mean that delays caused by the updating of information as experienced on all sites could be brought to a minimum. The scenario also showed how communication between site staff could be logged to enable the auditing of decisions. The research found that this could have different results on the behaviour of site staff. The recording could impact on the individuals involved in the decision-making process making them take greater care and time in reaching the final decision as the change could be traced back to them. This could also have an impact on the number of people being involved in the decision making process.

The behaviour of users when technology is introduced is an important factor which must be taken into account. Although a proposed system would be intended to help users, it may end up being discarded because of it being perceived as too risky. Research by Wikforss and Lofgren (2007) highlighted one of the reasons for poor usage of project extranets in Sweden to be the user reluctance to accept information, as knowledge of a task may imply responsibility. However, in Australia the research showed that the project team was happy to share and receive information as it was for the overall good of the project (Brewer et al., 2006). The inclusion of voice calls into the realm of project data along with the email must therefore take into account the resultant change in behaviour.

The use of voice as a means of data input brings about a few problems which can be addressed when considering similar research in other domains. When examining the use of voice the terminology becomes an important aspect when transcribing conversations into text. Special dictionaries for speech recognition engines would be needed to tackle this problem and minimise its effect. Another interesting issue raised during the case studies was behaviour on the phone. It was noted that when speaking one would possibly take longer to get to the point than if one were to spend time writing an email. In order to use voice as data input, the system would have to be able to sort through and extract the key phrases from a voice recording. Doing this with emails has been researched (Tedmori, 2006), with the same method applicable to the voice transcription, however this is an area which would require more exploration.

The research also examined the use of PDA's on site through the scenario and example screen shots distributed to the engineers during the case studies. When evaluating the use of such technology, the findings were similar to previous research (Bowden, 2005; Kimoto et al., 2005). Aspects of the device such as battery life, screen size and durability were raised as obstacles. With the use of the scenario, it was established that not all staff on the site would require such advanced technology. The scenario shows how general site staff can alert members of the team when problems are identified using VoIP technology. This can still be possible without giving them advanced PDA's. Other devices, such as dedicated VoIP phones can be suitable devices that enable contact but offer less risk associated with information access. Another barrier identified in earlier research (Ahsan et al., 2005) is security, construction sites being spaces difficult to secure leaving them vulnerable to the risk of thefts. Methods to minimise this include the use of RFID tags on devices and a logging system where devices are issued to users who would thereafter be responsible for it.

The research investigated potential barriers to the adoption of mobile computing, the main one being cost especially in terms of return on investment often difficult to quantify. A study that attempted to establish the cost of a VoIP deployment found this to be significantly cheaper than that of a traditional phone setup in all aspects of cabling, training, management, maintenance, telephone traffic and connection.(Corte et al., 2006). Another general problem raised by the participants was the complexity of some ICT support systems introduced within projects that sometimes require specialist knowledge not always available on site.

5.2 Requirements

From the three case studied, a number of requirements were identified to support the process of documenting change on site, these define the type of information and the way it is accessed.

These requirements are described in the next sections:

5.2.1 Fast and reliable communication

The mobile phone is the common tool used for communication as identified in the research (Ahsan et al., 2005, 2006), this is usually associated with high costs of network rental and handsets, these amounting to several millions for some companies (Ahsan et al., 2006). Although the cost of communication via this mean is continually dropping accessing data over this same infrastructure can lead to large bills. With the construction industry as any other industry attempting to cut costs in order to maximise profits, the long term use of the mobile phone may not be desirable. The use of alternative networks such as VoIP can provide long term savings, the establishment of advanced networks can achieve faster communication and bandwidth.

5.2.2 Efficient logging

The method of raising queries varied from site to site, however when it came to documenting changes, these were left to be completed by the engineers. Having a quick method to fill in documentation whilst away from the desk would provide a big advantage. The scenario identified voice as a possible means of data entry provided a system could transcribe the audio efficiently. As identified by Chen et al. (2007), the main difficulty here being the noise on the construction site which may hinder audio quality.

5.2.3 Access to information

One of the key requirements is access to important information such as drawings whilst away from the office. Although the PDA was found to have a small screen size, the engineers on site would still find this access beneficial for some tasks. Access to some specialised task information and other project related information such as health and safety guidelines were also cited as important.

5.2.4 Access to different systems

Of the construction companies studied, most were using some sort of IT tool to support information management and collaborative working. For a new mobile application to be successful, it should be able to interface with current tools and allow for smooth data exchange.

5.2.5 Ability to use rich media

The research found that images were a rich source of project data, however it was found that the data was not being disseminated among the project team. On the T5 site, many images were taken every day using digital cameras but instead of placing the images in a shared project database, they would remain on a desktop computer in the office. These would be used for specific tasks and eventually be filed away but not in searchable format as the images would not be tagged appropriately and hence offering little benefit to the management of the project. The use of images from the site can support collaboration, they can be used to help explain buildability problems to remote team members. The use of annotated pictures (as shown within the scenario) were strongly supported by the three companies and deemed desirable.

Allowing users to see live video, whether streaming from a hand held mobile advice for via a pre-set camera connected to the network, would give the ability to monitor and review tasks remotely. This was expressed as something that would be useful, and would increase in desirability as fuel costs continue to rise and companies attempt to become 'greener'. It must be noted though, that from the scenario evaluation, the use of cameras was identified as having potential problems, it may result in workers becoming nervous and therefore reluctant to undertake certain tasks. The use of cameras on site would therefore require further research to understand the effect on workers.

6 Proposed Solution

From the scenario evaluations and case studies, it is clear that there is a communication lapse between the construction site and the site office, causing delays in the logging of information and decisions when solving construction problems. The proposed solution aims to bridge the communication gap on site, allowing the sharing and use of multimedia content captered from mobile users.

The proposed solution will make use of both hardware and software to empower the mobile user making use of convergence to allow easy and fast data collection and exchange, and communication with other remote project team members. Although research has shown a slow use of project extranet systems (Yeomans, 2005; Brewer, 2006), this solution builds on the extranet model but offers additional toolsto support the mobile worker. The solution aims to make use of various technologies reviewed in the paper to support collaboration, including convergence with VoIP, speech recognition, mobile devices, and web services.

The proposed solution, named the Mobile Collaboration Toolkit (MCT), establishes the PDA as the main device for data collection and access on site. The PDA has the advantage of being portable and allows access to a variety of different networks and can include cameras and audio recorders for multimedia use.

The MCT architecture supports the mobile worker in a number of ways. Following a client-server model, a lot of the intense processing is handled by the server, leaving the client to handle fewer tasks and allowing it to act as a data collector/viewer as well as a communication device. The MCT supports a variety of data types including audio, video, text and documents allowing workers to share a large array of information whilst on site, for better and more efficient decision making. Speech recognition is used on the server to process audio information sent from the mobile client enabling users to quickly view audio content. This can help in both the searching of information and data capture as quick audio messages can be used instead of typed text.

The use of convergence with VoIP in the solution supports the mobile worker and the project team by allowing for quick communication between team members and those on site requiring information. The use of VoIP for voice communication (and potentially video communication) allows audio information to be retrieved along with other project data for better collaboration process and decision tracking.

Requests for information or project updates sent from the mobile client can be disseminated by the server with the use of RSS (Really Simple Syndication) allowing team members to subscribe to feeds, and with the use of RSS readers such as Microsoft Outlook be continually up to date with the latest messages sent to and from the construction site. Due to information being stored and displayed using the RSS standard, there is a greater chance of compatibility with existing extranets systems, therefore allowing the MCT to fit within the larger extranet infrastructure the construction site to be included within the larger project-wide collaboration framework.

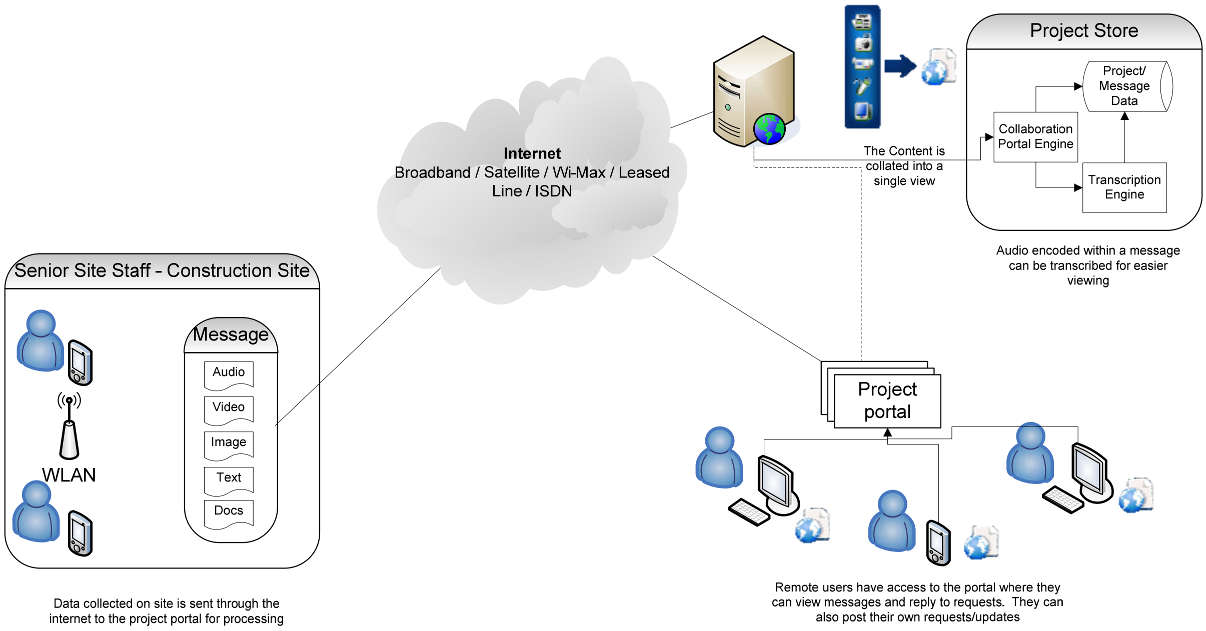

Figure 6 Conceptual model of proposed solution - Mobile Collaboration Toolkit (MCT)

Figure 6 shows how the MCT would fit within the construction process, with mobile workers able to collect and share information with remote team members, allowing the team to retrace and review decisions as and when needed and ensuring the project team is up to date with project progress

7 Conclusion

The research showed that although there were advances in ICT, there was little evidence of this on construction sites. Several problems with the collection and dissemination of information from the construction site were identified which impacted on the decision making process and hindered collaboration.

The requirements for an ICT support system were gathered with the use of case studies and scenario analysis. This led to the design of a potential solution which combined many of the advances in ICT including convergence, speech recognition, mobile devices, and web services to ensure the efficient flow of information and communication from the construction site. It was argued that such a system would allow for a greater degree of flexibility in information capture on site which would ensure a better understanding of problems occurring on site by the remote project team. Problems could then be resolved faster by having a greater number of the remote project team members contributing to decisions. The proposed system would ensure the entire collaboration process is recorded for a more accurate decision tracking and review.

Once the development of the solution is complete, it will be tested to examine how best it can be used on site and the effect it has on the collaboration process. The results would help fine tune the application to ensure maximum adoption.

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