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Report
Enabling Team Collaboration with Pervasive and Mobile Computing: A Review of Existing Mobile Computing Technologies

Research Project No: 2002-057-C-03 R

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EXECUTIVE SUMMARY

The application of Information and Communication Technology (ICT) in construction industry has been recognised widely by some practitioners and researchers for the last several years. During the 1990s the international construction industry started using with the increasing confidence information and communication technology. The use of e-mail became usual and web-sites were established for marketing purposes. Intranets and extranets were also established to facilitate communication within companies and throughout their branches. One of the important applications of the ICT in construction industry was the use of mobile computing devices to achieve better communication and data transmission between construction sites and offices.

Mobile computing is a generic term describing the application of small, portable, and wireless computing and communication devices. Generally, the device is designed for mobile workers who wish to have areal-time connection between a mobile device and other computing environment. The term mobile computing consists of three components: computer hardware, mobile networks and mobile services. With this in mind, mobile computing is also related to the mobile networks where the devices are connected.

The investigation of the use of mobile computing devices in construction industry was undertaken firstly in 1988 by looking at the potential of using 1-D barcodes for material management system. In 1990s, the academic and industrial sectors introduced Pocket PCs for field data collection. Since then, the use of handheld computers became popular in the jobsites. Wearable computer is identified by some researchers as another potential mobile device to support construction sites. Although mobile computers have been used in the construction industry for many years, the application of handheld computer in the jobsite has been very limited so far.

The selection of the appropriate hardware was identified as an important factor in the success of implementing mobile computing in construction, especially on-sites. Different type of hardware has different features and limitations. With their existing limitations, mobile computing should not be considered to be used as a general purposed computer. To choose an appropriate hardware for the construction site, people need to consider some hardware characteristics such as screen size, outdoor readability, battery power, physical unit size and robustness, primary storage, etc. Based on those characteristics, mobile computing hardware can be grouped into the following general categories: Laptop, Personal Digital Assistant (PDA), Handheld PC, Pocket PC, Wearable Computer, Tablet PC, Smartphone and Portable Computer.

To be effectively used in the construction sites, mobile computing should be supported by an appropriate software package. There are many software packages available on the market and each package will have strengths and

weaknesses. Software can be divided into two general classes: systems software and applications software. System software consists of low-level programs that interact with the computer at a very basic level such as operating systems, compilers and utilities for managing computer resources, whereas application software deals with database programs, word processors, and spreadsheets.

Accurate information on the right time and at the right place is crucial for a successful completion of the construction project. Generally, information in paper form is circulated within project participants during the construction process, and in many cases the information is not available when needed. Obviously, the information needs and the transmission of information amongst project participants have increased as projects have become more complex. Therefore, collaboration amongst them should be managed in an appropriate manner to ensure that everyone is in the “loop”.

Collaboration within project participants can be supported electronically by using web-based project collaboration which can bring significant improvements in organisations’ performance. Optus inCITE is one of the examples of the application of the web-based project collaboration which has been implemented by several large contractors in Australia for the last three years. Better project collaboration and communication amongst all participants can be achieved more effectively by equipping construction site personnel with mobile and wireless technologies which enable them to gain access to correct, accurate and up-to-date project information. Wireless technologies represent a rapidly emerging area of growth and importance for providing ubiquitous access to the network for all project participants. Studies show that organisations that integrate wireless networking technologies into their system experience increased productivity, better customer retention, and lowered operating costs. There are three types of wireless connectivity currently available such as personal area networks (PANs), local are networks (LANs), and wide are networks (WANs), which each is uniquely suited for different application and communication requirements.

Although the use of mobile computing devices was very limited in construction industry, several researchers and practitioners have looked closely at a number of the potential applications of mobile computing devices in the jobsites. The applications of barcoding system in the jobsites have been used since 1988 to support facilities management in an attempt to challenge the traditional centralised data storage method. The application of radio frequency identification (RFID) systems in the construction sites were identified in a few years later. RFID is a method of storing and remotely retrieving data using devices called RFID tags or transponders. By combining radio frequency identification technology with other information technologies, this technology can be suggested as an alternative system to replace traditional barcoding.

In 1990s, the use of handheld computer for timesheet entry, materials received, and daily inspection and reporting tasks became very popular in the construction jobsites. During that time, the implantations of handheld computers in construction industry have primarily focused on project management, schedule management, facility inspections, and field reporting applications. In addition to using mobile computing for inspection or reporting tasks, such devices have been also used by active workers on-site in order to support on-site construction activities.

Wearable computer was found to be one of other on-site applications that could potentially support inspection tasks. A wearable computer is a very personal computer. It should be worn like a piece of clothing, as unobtrusive as possible. A user should interact with the computer based upon context. It could be a communications device (immediate or store and forward), a recorder (visual, audio, other sensors) or a reference device (local or remote resources). Since 1998, wearable computer have been used to support construction jobsites on bridge inspections for highways and building constructions.

The applications of mobile computer are now gaining acceptance as useful tools at a construction site. Since the last five years, the usage of mobile computing in construction sites has been developing in many areas with a great support of different software applications. With the advance of technology and specific software applications, it is now possible to visualise substantial 3D models on mobile handheld computers in the field.

Mobile computing offers many benefits than can improve construction processes. The most significant benefit is the ability of the devices to provide construction workers with real-time access to relevant information at the construction sites. The benefits can be classified into two categories: tangible and intangible benefits. It is easier to quantify tangible benefits than the latter variety. A research conducted in USA showed that tangible benefits of using computer at workplace could saved time on paperwork and could spent more time on supervision between 36% and 50%. More benefits were identified as well by some other researchers in terms of using mobile computing on the jobsites. Although significant benefits of the applications of mobile computing have been identified, several barriers could limit the use of mobile computing in the construction sites. The barriers identified are related to technical, financial, cultural, organisational and legal.

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1. Introduction

It has been recognised widely that construction is an information intensive industry. The successful and timely project completion depends on the accuracy and timeliness of that information. In construction industry, project participants are normally located in different locations. As a result, the accessibility and transmission of critical project information can be difficult and potential to delays. In general, construction personnel who work on-site experience some difficulties in obtaining right information without physically walking to the construction site office. Moreover, Haas et al. (2002) stated that construction projects often experience extensive delays or rework due to information that is unavailable, inaccurate or simply outdated. The delays will, of course, decrease the overall construction project productivity and leading to cause indirect costs due to schedule delays or direct costs from rework.

With this in mind, it can be said that this is an urgent need of construction industry to provide their on-site construction personnel a tool that can provide accurate, reliable and timely information to all participants. In addition, the tool should have capabilities for those participants to contribute to the body of project information at any time, hence keeping the project information up to date. Mobile computing has now been identified as one of the great importance technologies for the construction sites to overcome such problems. Despite this, there are only just a few publications that address the use or potential of mobile computing in construction (Magdič et al., 2002). The advent of technology such as fax machines, mobile phones, and e-mail has aided in information exchange amongst project participants, but Haas et al. (2002) argued that technologies to benefit mobile workers are still in their infancy.

On a typical construction project, the objectives of the implementation of mobile computing in the construction sites are to add value to the constructed facilities, the contractor's business, the owner's company, or to other project participants. Significant effort is spent to ensure that time and money are not waste, and improve quality and working conditions. This paper aims at investigating the mobile computing devices, technologies, networks connectivity, information flow, all benefits, shortcomings and also barriers of the application of this new technology.

2. Mobile Computing

2.1 Term of Mobile Computing

Mobile Computing is a generic term describing the application of small, portable, and wireless computing and communication devices. This includes devices like laptops and handheld devices (mobile phones, personal digital assistant, etc). Different people may have different perceptions in relation to the term of mobile computing. Basically, mobile computing is a computing paradigm designed for mobile workers and other who wish to have a real-time connection between a mobile device and other computing environment. Magdič et al. (2002) stated that the term mobile computing consisted of three important components: computer hardware, mobile networks and mobile services. In other words, Magdič et al. (2002) stated that mobile computing did not only involve mobile computing devices such as laptops, notebooks, PDAs and wearable computers, which are designed to be carried around, but it also related to the mobile networks where these computers were connected. Zimmerman (1999) described that the term mobile computing was used to describe the use of computing devices to interact with a central information system, which was normally identified as fixed workplace, while the users away from that place. With this technology, the mobile worker enables to create, access, process, store and communicate information without being constrained to a single location.

2.2 Mobile Computing Hardware

Hardware selection was recognised early by many previous researchers as an important factor in the success of implementing mobile data capture in construction (Ward et al., 2004). Citing factors such as screen size, outdoor readability, battery power, physical unit size and robustness have been identified as important considerations in the selection of appropriate hardware for the construction site.

Due to the existing limitations of portable devices/mobile devices (limited computational power, disk space, screen size, etc), it can be claimed that mobile devices should not be considered general-purpose computers. For example, a user cannot be expected to run complex simulations or compile and link huge software systems on these devices. Even though mobile devices will become increasingly powerful, they will never match the computational power and facilities available on typical desktop machines. In other words, it can be said that mobile computing fundamentally differs from desktop computing. Mobile devices including PDAs, mobile phone and pocket PC, when compared to desktop computers have low computational power, small memory and often no mass storage (Jadid and Idress, 2005).

2.2.1 Types of Mobile Computing Hardware

Mobile computing is accomplished using a combination of computer hardware, system and application software and some form of communication medium. Zimmerman (1999) argued that the characteristics of mobile computing hardware are defined by the certain types of features such as:

- Size and form factor;
- Weight;
- Microprocessor;
- Primary storage;

- Secondary storage;
- Screen size and type;
- Means of input and output;
- Battery life;
- Communication capability;
- Expandability; and
- Durability of the devices.

By using the above characteristics, mobile computing hardware can be grouped into the following general categories such as: Laptop, Personal Digital Assistant (PDA), Handheld PC, Pocket PC, Wearable Computer, Tablet PC, Smartphone and Portable Computer. The characteristics of the mobile devices are described briefly as follows.

Laptop

A laptop computer, also known as notebook computer, is a small mobile personal computer which usually weighing from 1 to 3 kilograms. Laptops usually run on batteries, but also from adapters which also charge the battery using mains electricity. Laptops are capable of many of the same tasks that desktop computers perform, although they are typically less powerful for the same price. In addition to a built-in keyboard, they may utilise a touchpad (a trackpad) or a pointing stick for input. An external mouse or keyboard can usually be attached as well.

Laptops are very suitable for taking from one working place to the next, but not for working while on the go. Laptops are not designed to survive a harsh environment as the construction site, where the device can be dropped and pushed, where it is exposed to the weather and where is no energy supply. Figure 2.1 shows the example of a laptop.

Figure 2.1 Laptop Computer

Personal Digital Assistant (PDA)

Personal Digital Assistants are handheld devices that were originally designed as personal organisers, but became much more popular over the years. A basic PDA usually includes a clock, date book, address book, task list, memo pad, and a simple calculator. Many PDAs can access to the Internet via Wi-Fi or Bluetooth technology. One major advantage of using PDAs is their ability to synchronise data with a PC or home computer.

The performance and functionality of the PDA can be increased by extra software and hardware add-ons. For example, users can download applications from internet to view graphics, play or read e-books.

Different types of PDAs with different types of operating systems, such as Windows CE, Palm OS, BlackBerry, Symbian OS, and Linux can be found on the market.

The size of PDA is about 5.11” x 3.28” x 0.62” and therefore fits comfortable into the palm of human being (See Figure 2.2). The weight is about 6.5 oz. The PDA has a TFT black and white or colour display with a touch screen. In general they are equipped with an infrared port and optional they contain an USB port. The package of the PDA comes with a docking cradle to connect the PDA with the desktop PC. There are many different types of input data methods of a PDA. These include:

- Handwriting by a stylus pen,
- An extra fold-keyboard or soft keyboard,
- Hard and soft buttons and
- Voice recording.

Figure 2.2 Personal Digital Assistant Device

Handheld PC

Handheld PC is a combination of laptop and PDA. It comes with a fold down keyboard. As a PDA it serves as a mobile electronically notebook, but is more powerful as a PDA in general. Handheld PC is smaller than any standard notebook PC or laptop. A true Handheld PC runs on a Platform Release of the Microsoft Windows CE operating system. Originally announced in 1996, the handheld PC is distinctive from its more recent counterparts such as the Palm-Size PC, Pocket PC, or SmartPhone in that specification provides for larger screen sizes as well as a keyboard. The characteristics of a Handheld PC are as follows:

- Run Microsoft's Windows CE;
- Use ROM;
- Have a screen supporting a resolution of greater than 480X240;
- Include a keyboard, a CF Slot, a PCMCIA Slot, an infrared (IrDA) port; and
- Provide wired serial and/or USB connectivity.

Figure 2.3 shows examples of handheld PC available in the market.

Figure 2.3 Handheld PCs

Pocket PC

According to Microsoft, the Pocket PC is a handheld device that enables users to store and retrieve e-mail, contracts, appointments, play multimedia files, exchange text messages with MSN Messenger, browse the Web, and more. In other words, a Pocket PC is a handheld-sized computer that runs a specific version of the Windows CE. It has many capabilities of modern desktop PCs. Pocket PCs can also be used with many other add-ons like GPS receivers, barcode readers, and cameras. A Pocket PC must include a touchscreen and directional pad or touchpad (See Figure 2.4).

Figure 2.4 *i*-Mate PDA2K Pocket PC

Wearable Computer

A Wearable computer is a lightweight computer with all the functionality and connectivity of a full functioned networked desktop PC. It is supposed to be worn at the body of the user and to leave the user's hand free for other activities while using the computer (See Figure 2.5).

Equipped with a touch screen flat panel colour display, head mounted colour display (See Figure 2.6) with hands-free voice recognition and activation, the full-function of a wearable computer makes it possible for workers to access data, file reports, send e-mail and connect with the internet virtually anywhere. Operation can be performed non-stop, without interrupting a worker by looking away or letting go of a safety grip. Depending on the application, the primarily input to a wearable might be a chording keyboard, gesture, speech recognition or even just passive sensors (context awareness). Output might be presented via speech, audio tones, a head-mounted display or haptic output. Output can also be combined with the physical world through a visual or audio augmented reality interface.

Wearable computers are especially useful for applications that require computational support while the user's hands, voice, eyes or attention are actively engaged with the physical environment. The largest differences between wearable and other mobile computing platforms are the human-computer interface.

Even that the wearable computer promises great mobility while using them the technology is not commonly used yet. Several companies and research institute use them mainly for development purpose. The technology is still in its infancy and considered too expensive by the industry and worth the money only for specific applications where they accomplish a great job.

Figure 2.5 Wearable Computer **Figure 2.6 Head-Mounted Display**

Tablet PC

A Tablet PC is a type of notebook computer that has an LCD screen on which the user can write using a special-purpose pen, or *stylus* (See Figure 2.7). The handwriting is digitised and can be converted to standard text through handwriting recognition, or it can remain as handwritten text.

Users can use the pen directly on the screen just like a mouse to do things like select, drag, and open files; or in place of a keyboard to handwrite notes and communication. Unlike a touch screen, the Tablet PC screen only receives information from a special pen. Tablet PCs that include a keyboard are called *convertibles* or *hybrids*. Ones that are only a monitor with pen are called *slate*; they can use external wireless or USB keyboard.

Most Table PCs run on the Windows XP Tablet PC Edition operating system. Version 2005 brought improved handwriting recognition, and improved the Input Panel, allowing it to be used in almost every application

Figure 2.7 Toshiba Portege 3500 Tablet PC

Smartphone

Smartphones or Smart Devices have been introduced into the mobile phone market to create as all-in-one device that combines the functions of mobile phone with the features of a PDA. PDA-based devices usually have a touch-screen for pen input, smartphones usually have a standard phone keypad for input. In addition, smartphones usually have larger displays and more powerful processors. The first smartphone was released to the public in 1993. Besides a mobile phone, it also contained a calendar, address book, world clock, calculator, notepad, and e-mail. Users could also use a stylus to write directly on its screen to create facsimiles and memos. Most common operating systems are Symbian, Palm OS, Windows Mobile, BREW, and Linux. Figure 2.8 shows an example of a smartphone.

Figure 2.8 Nokia 3620/3660

Portable Computer

A Portable computer is a computer that is designed to be moved from one place to another. The term portable computer is now almost exclusively used to refer to portable computers that are larger than a laptop, often use conventional parts and usually do not run on batteries. Portable computers have been increasing in popularity over the past decade, as they do not restrict the user in terms of mobility as a desktop computer would. Wireless Internet, extended battery life and more comfortable ergonomics have been factors driving this increase in popularity (See Figure 2.9)

Figure 2.9 Portable Computer

2.2.2 How to Choose a Mobile Device/Handheld

There are some different features and specifications to consider when people choose handheld devices on the market. The main decisions that people have to make are on memory, display, size, interface, battery, and additional functionality.

Memory

Memory is a key consideration for mobile computing. It stores the operating system, application software, and data. Memory needs are depend on the operating system employed and application requirements.

Display

Mobile computers use LCD (Liquid Crystal Display) backlit screens that are basically the same as those used in laptop computers. Since the screen is the key interface between the users and their information, choose a mobile device with one that can display the data needed to complete a task. Colour devices tend to be easier to read and are certainly more appealing for Web surfing. The quality of colour screen varies by device.

Size

As with other types of computers, there is a trade-off between size, power and cost. Overall Palm OS devices tend to be smaller and less expensive than Pocket PC devices. Because it is less resource-intensive, the Palm OS can run well on a device with less processing power than would be required to run Pocket PC. Carefully consider whether users want a device that can be taken everywhere and how large of a device users are willing to carry.

Interface

Most handheld devices provide users with two means of entering information. Users can either use a stylus to tap the letters of a keyboard that pops up on the screen, or to enter in stylised letters that are easy for the handheld device to convert into text. The stylus is also required in order to navigate around the screen. Some of the newer handheld computers such as Treo and the Sharp Zaurus SL-5500 are beginning to take advantage of small thumb-keyboards similar to those that have become popular with two-way pagers. Thumb keyboards are also available as add-ons for many other handhelds. Even with the keyboard, it is still necessary to use the stylus for page navigation, but this type of interface removes the inaccuracies occasionally involved in handwriting recognition.

Batteries

Power for the mobile computer comes from a removable battery pack. Many models also include a small back-up battery to protect users from memory loss should the main batteries fail while users are using their mobile devices.

Additional Functionality

Over the past years, handheld devices that integrate cell phone/modem functionality have become increasingly popular. Integrated devices tend to be larger and more expensive than their non-wireless counterparts but are usually a more streamlined and cost-effective option than purchasing a separate handheld device and wireless modem. Most non-integrated handheld devices currently in production can be made wireless, either by means of adding a clip-on modem or by using an existing cell phone as a modem. As handheld computers have gained increasing popularity the number of available accessories has increased dramatically. Built-in and add-on modules are now available that can turn a basic handheld device to a digital camera, a cell phone, a bar code scanner, a fax machine or a GPS receiver.

2.2.3 Operating Systems

In computing, an operating system (OS) is the system software responsible for the direct control and management of hardware and basic system operations. Additionally, it provides a foundation upon which to run application software such as word processing programs, web browsers and others.

Every general-purpose computer must have an operating system to run other programs. Operating systems perform basic tasks, such as recognising input from the keyboard, sending output to the display screen, keeping track of files and directories on the disk, and controlling peripheral devices such as disk drives and printers (See Figure 2.10).

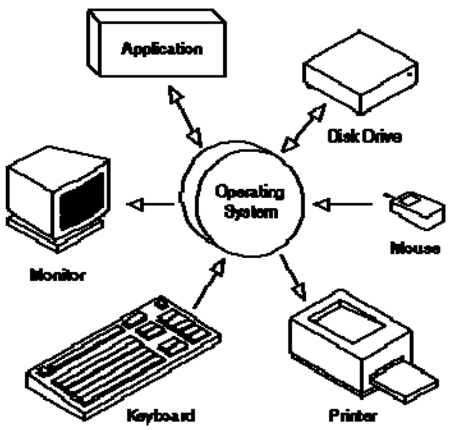

Figure 2.10 Operating System Basic Tasks
(Source: www.webopedia.com)

For large systems, the operating system has even greater responsibilities and powers. It is like a “traffic cop” – it makes sure that different program and users running at the same time do not interfere with each other. The operating system is also responsible for security, ensuring that unauthorised users do not access the system.

Operating systems can be classified as follows:

- **Multi-user**: A multi-user Operating System allows for multiple users to use the same computer at the same time and/or different times to run programs.

- **Multiprocessing**: An Operating System capable of supporting and utilising more than one computer processor.

- **Multitasking**: An Operating System that is capable of allowing multiple software processes to be run at the same time.

- **Multithreading**: Operating Systems that allow different parts of a software program to run concurrently.

- **GUI** (Graphical User Interface): A GUI Operating System contains graphics and icons and is commonly navigated using by using a computer mouse.

Below are some common Operating Systems available on the market: Windows XP Professional, Windows XP Home, Windows 2000, Windows ME, Windows CE, DOS, Linux, Mac OS, Symbian OS, Palm OS, etc. The list of Operating Systems can be found in more details on http://en.wikipedia.org/wiki/List_of_operating_systems.

2.2.4 Mobile Computing Operating Systems

The operating system is the backbone of the mobile computing device. Several operating systems are available for mobile computers, but the most common ones are Microsoft's DOS Operating System, Windows CE or Pocket PC, Palm Operating System, and Linux. Other operating systems are Symbian OS, Mobilinux by Montavista, and Newton OS (http://en.wikipedia.org).

DOS

DOS is a convenient and powerful operating system. Because of its industry-standard architecture, it enables efficient programming and development of demanding and information-intensive applications. However, it is a single-user operating system, running only one program at a time.

Windows CE

Windows CE is basically a miniature version of Windows, designed specifically to work with mobile computing devices. The look and feel of

Windows CE is very similar to Windows 95/98. A multi-tasking OS, Windows CE devices offer more memory and more functions than devices based on the DOS OS.

Windows Pocket PC

Pocket PC is a version of the Windows CE operating system. Devices running on the Windows powered Pocket PC platform have a new, easier-to-navigate user interface. They also feature extensive Internet browsing capabilities, and powerful overall performance.

Palm OS

The Palm Operating System runs multiple programs at one time and enjoys a reputation for simplicity, operating speed and easy customisation through third-party software add-ons. The Palm OS is an open standard operating system and has been licensed for use to many mobile computing manufacturers.

Embedix (Linux)

Until recently only a desktop-bound operating system, Linux has also made the jump to the handheld arena in a branded version called Embedix. It is currently offered only on Sharp's Zaurus SL-5500, targeted at enterprise users.

2.3 Mobile Computing Software

Today software is at the heart of most technology that people regularly use without a second thought. Software enables all kinds of data collection, storage, and management, data transfer, and voice communication. Measurable benefits include reduced cost and leverage functionality – software often is what allows people to get more advantages to complete their project's goals.

Traditionally, business software applications for construction dealt with either finances or operations. This included software to assist with things like biding and estimating, payroll and accounting on the financial side, and project management and scheduling on the operations side.

All project management solutions are not created equally. Each package will have strengths and weaknesses. When evaluating project management software from an integration standpoint, there are several things to consider: (1) Level of Integration; (2) Document Imaging; (3) Remote Access; (4) Product Evolution; and (5) Training and Support (Trenchless Technology, 2003).

Integrated project management software bridges the gap between the accounting staff and project managers. By sharing a common database of information, both have access to the same at the same time without duplicating effort or data entry. Use of integrated project management software creates a consistent process for recording data and managing information (Trenchlessonline.com).

Software can be divided into two general classes: *systems* software and *applications* software. Systems software consists of low-level programs that interact with the computer at a very basic level. This includes operating systems, compilers, and utilities for managing computer resources (http://www.webopedia.com/TERM/A). In contrast, applications software (also called end-user programs) includes database programs, word processors, and spreadsheets. Figuratively speaking, applications software sits on top of systems software because it is unable to run without the operating system and system utilities.

The development of software applications for mobile computers has been recently stimulated by the availability of more powerful operating systems and the transfer of standardised programming languages on ever-smaller computing platforms.

A study conducted by Vivoni et al. stated that for disciplines with an active field work component, providing software tools that improve the accuracy, efficiency and quality of the data collection process can significantly improve current practices. In addition, using accurate technology will allow users to link real-time field data collection from various devices to a centralised data server located at a remote location. This capability can lead it improvements in the management of deployed field teams. The objective of the mobile software applications is to streamline the collection process and improve the accuracy of environmental field data as compared to current practices. The software available on market can be seen in Appendix A.

2.4 Mobile Computing Specifications for Construction

Mobile computing hardware comes in many shapes and sizes. There are some requirements to make a mobile computer suitable for use at the construction site. The computer device needs to be portable and be able to be carried in one hand, robust and weather resistant (be able to be in the rain). The device should have long lasting battery to be used for one whole working day without a need to recharge the battery. Desirable would be functions as hand free usage and speech recognition (Eisenblaetter, 2001). In addition, the screen must be visible in bright sunlight and near darkness; and the device must be able to survive being dropped from about 1 m into a hard surface. This hardware is known as Rugged Computers (See Figure 2.11) and the application of the rugged computer in construction site can be seen in Figure 2.12.

Scribe Centrino, Rugged Tablet

Rough Rider III, Rugged Laptop

Fully Rugged Handheld Computer

Husky FS/2

Figure 2.11 Examples of Rugged Computers

Figure 2.12 Application of Rugged Computer On-site

Moreover, the researchers believed that combining features such as dual digital cameras, a Global Positioning System (GPS) receiver, inclinometer, digital compass, touch screen and pen interfaces, bar-code reader, and wireless radio/mobile communications – all integrated into the single handheld devices – will allow users on-site to, for instance, take easy measurements of construction objects from instantaneous digital photographs (allied with the accurate location and orientation of camera and object), and to provide this information to other stakeholders working across or off-site.

Alexander et al. (1998) argued that in order to effectively “complete the loop” between designers, engineering contractors, and constructors the current level of computer-awareness of potential users on a construction site must be raised, and the approach recommended is one of tailoring hardware and software systems to provide purpose built tools for specific uses. Research has shown (Coble, 1994) that such a system must be closely integrated so that carrying and fitting additional parts and cables does not burden the users.

When considering the use of handheld computers at the construction site, the devices must be able to endure the harsh working conditions and abuse inherent in the mobile nature of the work and the environment. The following are the characteristics that a device must possess in order to function within a construction environment and meet the needs of the workers:

- Must attach to a belt;
- Must have a long battery life;
- Must have a display visible in sunlight;
- Must be ragged (i.e. splash, fall, dust, and heat resistant);
- Must be easy to operate;
- Must fit in the palm of one hand;
- Must be multi-functional;
- Must have a suitable interface (touch screen or voice recognition);
- Must be lightweight so as not to cause fatigue after prolonged use;
- Must have sufficient memory;
- Must be mobile; and
- Must be intrinsically safe if necessary.

3. Project Collaboration

Collaboration refers to mutual efforts by two or more individuals who perform activities in order to accomplish certain tasks. The individuals may represent themselves or organisations, or they may be members of a team or a group. The group can be permanent or temporary and it can be in one location or in several. If group members are in different locations, it can be said as a virtual group, and they conduct virtual meeting, as they “meet” or communicate electronically. Collaboration within groups of people can be supported electronically by several technologies. Web-based collaboration is a general term which refers to the use of Web-related technologies for the purpose of allowing defined groups of people to meet or share information. This can be done in either a public or private manner, depending on the needs of the group.

Numerous studies suggest that collaboration is a set of relationships that can bring significant improvements in organisations' performance. The construction process relies on effective project collaboration and there are clear benefits to the electronic sharing of access to project drawings, plans and other documents. Improved communication between designers and contractors can shorten tendering and construction time. In addition to cutting printing and postage costs people will also reduce the risk of losing drawings and easily be able to track and document all communication and design decisions. However, the majority of construction business processes are heavily based upon traditional means of communication such as face-to-face meetings and the exchange of paper documents in the form of technical drawings, specifications and site instructions (Stewart and Mohamed, 2004). The need to increase the efficiency of these processes via exchanging massive volumes of information at high speed and at relatively low cost has been long recognized by the industry (Deng et al., 2001).

Alexander et al. (1998) believed that a coordinated system for exchanging information amongst project participants in the Architecture, Engineering and Construction (AEC) sector was urgently needed. They argued that much time and effort was wasted in converting or re-entering information that has already been entered into another program. Moreover they stated that to gain maximum benefits of an integrated approach, then data entered at one stage of the process should be available at other stages for further use or subsequent refinement – without the need to re-enter it (see Figure 3.1).

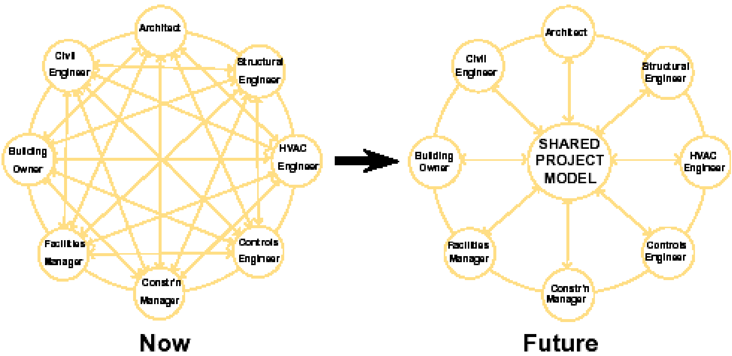

Figure 3.1 Improved Project Communications (Source: Alexander et al., 1998)

The obvious solution to this array of communication problem is to develop a vendor neutral interchange format that allows the entire project participants with their different computer program to exchange information into and out this neutral format. Optus inCITE is one of the examples of the application of the web-based project collaboration. Optus inCITE is a neutral construction industry trading exchange that is available to the construction industry as a whole, and which comprises the three applications that are grouped under a single portal (Taylor, 2004). The benefits of project collaboration can be found more details in Figure 3.2.

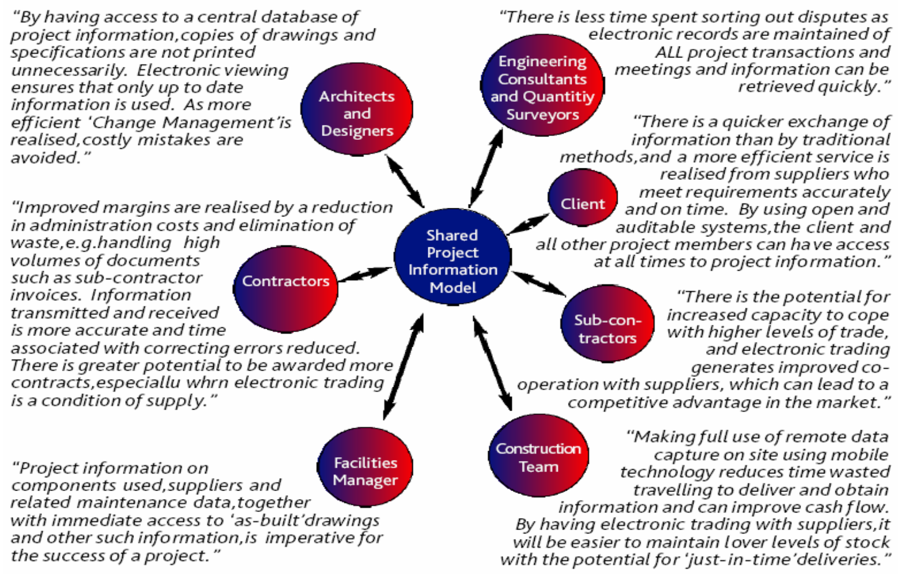

Figure 3.2 Benefits of Project Collaboration
(Source: CITE)

Despite the many potential benefits, web-project collaboration is moving ahead fairly slowly. Reasons cited a various studies include technical reasons; security and privacy concerns; internal resistance; and lack of internal skills to conduct collaboration electronically. Organisational culture shock is another barrier to implement project collaboration successfully. People normally simply resist sharing. One reason is the lack of trust, especially in ad-hoc relationships.

In order to achieve better project collaboration and project communication amongst all participants and to complete the loop between design office and construction site/office and ensure that key project information once collected is retained for use by others, Alexander et al. (1998) said that construction industry have to give personnel on the construction site, or in the field, the ability to collect and provide, or to gain access to, correct, accurate and up-to-date project information. In other words, they believed that the project information loop must be supported by mobile or wireless technologies.

4. Communication Technologies and Information Flow

Communication between project participants must occur frequently and effectively to ensure a successful project completion. Traditionally, the information flow in construction industry relies on paper and documenter's memory (Coble, 1994), but this process often introduces errors due to data loss or unintelligible field notes or incomplete recollection of information.

On a typical construction project, information flows from top level to the lower level. The lower level is normally received information such as working instruction, tasks, specifications or construction drawings to be executed. Information that flows up the hierarchy is typically only what is requested by management from the higher level position. This situation limits the workers and/or supervisors' abilities to communicate with management (Oglesby et al., 1989).

Currently, information is often "lost" in the sense that vital information is not retained for easy re-use and must be re-entered, or bulky manuals and drawing folios must be carried, to ensure the employee working out of the office has rapid access to the information needed to perform some of their tasks (Weippert et al., 2002). In the construction industry, Neogroponte (1975) mentioned that lack of information was identified as a major problem during the design stage. The lack can be caused in two ways such as (1) information does not exist and must therefore be created; and (2) the information exists and must be made available at the right time and place. In order to solve the first problem general use of computer in construction can be applied. Information can be created by synthesis and analysis. For the second cause, computer integrated system needed to be implemented.

Australia, in particular, is a large country with dispersed projects and team members usually headquartered in the major cities and regional centres. Extensive travel is therefore necessary, with inefficiencies in time and delays in decision-making. Hence, Weippert et al. (2002) strongly argued that more innovative IT (Internet-based) communication technologies could be used to help improve the flow of project communications to ensure: that communications occur in a controlled, timely and less costly manner than would traditionally be the case; that information leakage is kept to an absolute minimum; and that all members of the project consortia are in possession of the most up-to-date and accurate project information (Figure 4.1)

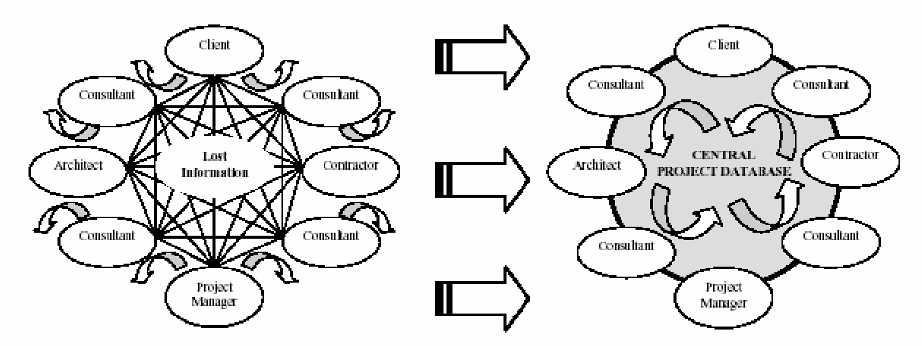

Figure 4.1 Traditional vs Central Project Database (Weippert et al., 2002)

There are many communications technologies available today that enable mobile computers to communicate. The most common of these technologies are:

- Wireless Local Area Networks (WLANs);
- Satellite;
- Cellular Digital Packet Data (CDPD);
- Personal Communications Systems (PCS);
- Global System for Mobile Communications (GSM);
- RAM and ARDIS data networks;
- Specialised Mobile Radio (SMR) service;
- One and two-way paging;
- Plain old telephone system (POTS);
- Internet;
- Infra-red;
- Docking (serial, parallel, LAN); and
- Disk swapping.

4.1 Mobile Communications

Early development of mobile devices restricted the users to a limited selection of available communication technologies (Ward et al., 2004). The simplest form being the connection of two or more computers using hardwired means such as a docking station, serial or USB port. This was later enhanced by the introduction of infrared technology. Further developments have led to the amalgamation of mobile computing devices and mobile telecommunications protocols, with PDA's now available with integrated mobile connectivity or via a separate mobile phone, though either a wired or wireless connection such as Bluetooth. This provides the mobile users with the ability to upload and download data from anywhere that a mobile signal is provided. The currently available technologies for mobile data transfer are Circuit Switched Data (CSD), High Speed Circuit Switched Data (HSCSD), General Packet Radio Systems (GPRS) and Third Generation (3G).

CSD is the original protocol used for data transmission over Global System for Mobile Communication (GSM) mobile communications networks. Maximum transfer rates vary between 9.6 kbps and 14.4 kbps depending on the mobile phone handset and the service provider in use. HSCSD is essentially a high-speed implementation of GSM, with some service providers offering a theoretical transfer rate of up to 57.6 kbps.

GPRS is a packet switched "always on" technology supporting Internet Protocols (IP) and is typically 2 to 3 times faster than CSD with a theoretical maximum speed is about 170 kbps. Because GPRS uses the same protocols as the Internet, the networks can be seen as subsets of the Internet, with the GPRS devices as hosts, potentially with their own IP addresses. In practice, connection speeds can be significantly lower than the theoretical maximum, depending upon the amount of traffic on the network and the type of handset being used, meaning that people can get higher GPRS rates in the evening and at night. However, GPRS services should be cheaper than circuit-switched connections, with the network only being used when data is being transmitted.

3G is an emerging broadband packet switched technology currently being targeted at picture and video streaming applications on mobile handsets. Data transmission speeds are dependent upon the environment the connection is being made with speeds of up to 2 Mbps (Megabits per second) achievable in indoors and stationary environment. However, for high mobility such as required in construction, these rates can be reduced to as little as 144 kbps.

Established technologies such as CSD, HSCSD and GPRS allow for the transfer of data to and from mobile devices on site to remote locations such as head-office. However, this requires data to be stored locally on the device during work, potentially placing collected data at risk if the device is damaged or, in the case of mobile devices, loose battery power and hence state. Such limitations require the user to be in active control of the data and the state of the device, increasing the complexity of the data collection task. Whilst the advent of 3G may allow true mobile thin-client capabilities for site users, issues with respect to signal coverage, speed and costs still remain.

4.2 Wireless Communications

Studies show that organisations that integrate wireless networking into their systems see increased productivity, better customer retention, and lowered operating costs. It is an environment where high-performance networking enables total business mobility. From any location or within a company, using a notebook computer or handheld device, people can wirelessly gather information, connect with colleagues, interact with customers, and make informed decisions in real time.

The use of wireless technology in industrial environments is less widespread, although there are many benefits:

- Reduced installation time and costs,
- Reduction in space needed for cabling,
- More flexibility for locating equipment,
- Less disruption when networks are reconfigured, and
- Provision of location information

There are three types of wireless connectivity currently available: personal area networks (PANs), local area networks (LANs), and wide area networks (WANs). Each is uniquely suited for different application and communication requirements.

Personal Area Networks (PANs)

Personal area networks are based on a global specification called Bluetooth, which uses radio frequency technology to transmit voice and data. Bluetooth is being developed by the Bluetooth Special Interest Group established in 1998. Bluetooth is ideal for mobile professionals who need to link notebook computers, mobile phones, PDAs, and other handheld devices to do business at home, on the road and in the office.

Local Area Networks (LANs)

A wireless local area network is a flexible data communication system implemented as an extension to, or an alternative for, a wired LAN within a building. A few of today's wireless LANs combine voice and data communications over the same backbone for lower costs and more effective and immediate information sharing; as well as high-speed networks for large file transfers and video streaming. Users can roam from cell to cell, capture and send data; access the Internet and the corporate intranet.

Wide Area Networks (WANs)

Wide area networks utilise digital mobile phone systems to access data and information from any location in the range of a cell tower connected to a data-enabled network. Using the mobile phone as a modem, a mobile computing device such as a notebook computer, PDA, or a device with a stand-alone radio card, can receive and send information from a network, corporate intranet, or the Internet. It enables communications from a construction site, a conference centre, an airport, or even a train.

4.2.1 Wireless Internet Service Providers

The ability to wirelessly receive and transmit data back to "home base" depends on having the right Wireless Internet Service Provider (WISP) (www.xb.com). In Australia, even though there some WISP, the most popular wireless internet service providers are Telstra, Optus and Vodafone. There are several particular issues to consider supporting data transmission in the construction industry: coverage, network type, speed, security, hardware and billing.

Coverage

The single most important factor involved in choosing a wireless service provider is coverage. Users' modem will neither receive nor transmit data if they are in the area that does not receive a signal compatible with their wireless modem. The Vodafone GSM/GPRS network covers up to 92% of the Australian population. Telstra network covers more than 96%, whereas the coverage area of Optus network is over 95% of the Australian population.

Network Type

Each wireless service provider is part of a particular network. Unlike the phone system, the wireless networks do not all use the same communications technology. The network type chosen mainly affects the roaming options. Examples of network types are CDMA, CDMA1X, GSM, GPRS, or Satellite.

Speed

Data is transmitted at widely various speeds over different wireless network types. Wireless Internet Service Providers normally advertise the theoretical speed of their network, where this speed is rarely attained in actual use.

Security

To wirelessly access resources on the corporate network, users will probably need to navigate through a firewall and/or other security measure first. The choice of service provider is not an issue for security measures such as VPN that support all network types. It might be an issue for navigating through the firewall.

Hardware

Some cell phones and modems allow data transmission on more than one frequency (in the case of GSM) or more than one variation of a standard (CDMA vs CDMA1X). Some allow voice transmissions to travel over more than one type of network (CDMA or GSM vs analog). But very few modems will allow data transmission on two widely different networks. As a result, the choice of service provider/network will directly relate to the hardware that chosen.

Billing

For the most part, data transmission is billed based on either the number of minutes that it takes for the data to be transmitted, or on the quantity of data that is sent and received.

4.2.2 Wireless Technology

Wireless technologies represent a rapidly emerging area of growth and importance for providing ubiquitous access to the network for all project participants. Recently, some industry made significant progress in resolving some constraints to the widespread adoption of wireless technology. Some of the constraints have included disparate standards, low bandwidth, and high infrastructure and service cost. Wireless technologies can both support the company mission and provide cost-effective solutions. Wireless is being adopted for many new applications: to connect computers, to allow remote monitoring and data acquisition, to provide access control and security, and to provide a solution for environments where wire may not be the best solution.

As with any relatively new technology, there are many issues that affect implantation and utilization of wireless networks. There are both common and specific issues depending on the type of wireless network. Some of the common factors include electromagnetic interference and physical obstacles that limit coverage of wireless networks, while others are more specific, such as standards, data security, throughput, ease of use, etc.

The application of the wireless technologies can be divided into the following:

- Voice and messaging,
- Hand-held and other Internet-enabled devices, and
- Data Networking.

Cell phones, pagers, and commercial two-way business radios can provide voice and messaging services. These devices may be based on analog or digital standards that differ primarily in the way in which they process signals and encode information. The analog standard is the Advanced Mobile Phone Service (AMPS). Digital standards are Global System for Mobile Communications (GSM), Time Division Multiple Access (TDMA), or Code Division Multiple Access (CDMA).

Internet-enabled cell phones and Personal Digital Assistants (PDA) have emerged as the newest products that can connect to the Internet across a digital wireless network. New protocols, such as Wireless Application Protocol (WAP), and new languages, such as WML (Wireless Markup Language) have been developed specifically for these devices to connect to the Internet.

In order to relieve the burden of uploading, downloading and synchronisation required by other communications technologies, it is necessary to implement thin-client applications (Ward et al., 2004). This can be achieved through the use of currently available wireless networking technologies. Technologies such as IEEE 802.11b utilise radio waves for the transfer of data and allow communication speeds up to 11Mbps, which is far in excess of any other mobile communication technology. Whilst the indoor use of IEEE 802.11b has found popularity for replacing traditional wired LAN, the protocol is now being applied in open environments with emergence of outdoor public wireless local area networks (WLAN). Known as “Hot-spots” these provide high speed internet access in densely populated areas such as airport lounges, railway stations and hotels to mobile corporate and private user. This technology has allowed, for the first time, users to operate functionality as a mobile thin-client without the restraints of slow dial-up connections. However, its application within construction environment has been little exploited.

GPRS (General Packet Radio Service)

The GPRS is a new non-voice value added service that allows information to be sent and received across a mobile telephone network. Theoretical maximum speeds of up to 171.2 kilobits per second (kbps) achievable with GPRS using all eight timeslots at the same time. This is about three times as fast as the data transmission speeds possible over today’s fixed telecommunications networks and ten times as fast as current Circuit Switched Data services on GSM networks. Immediacy is one of the advantages of GPRS when compared to Circuit Switched Data.

GPRS is a packet-based wireless communication service that promises fast data rates and continuous connection to the Internet for GPRS capable devices. GPRS uses a more efficient way of sending and receiving data information. Unlike circuit switched services, it does not require a dedicated channel for the length of the data transmission. Rather, it breaks the information into “packets”, allowing multiple users to make use of many channels at once. As a consequence, GPRS offers a cost-effective method of sending information.

GPRS is a wireless technology that uses the existing mobile phone network to allow laptops and handhelds, have *always on* connectivity, everywhere. The map of GPRS coverage in Australia follows broadly GSM availability. Rates, service and options differ by carrier, but generally people can expect to be able to access GPRS from anywhere users can get a mobile phone signal. With GPRS users can send and receive e-mail at anywhere; access the web, the company intranet; download files, upload orders and update databases; and more.

To connect to the GPRS network, people need a GPRS enabled device and a GPRS account with a telecommunications provider to access the service. Many mobile phones now come with GPRS connectivity built in. Bluetooth and WiFi make it possible to share the internet connection (GPRS) with trusted laptops or handheld’s. Some PDA’s have built in GPRS which allows them be online. Most GPRS devices afford connections similar to a dial up modem. Devices usually have four, but some have 10 GPRS channels, each allowing 9.6Kbps. Typically people will connect to GPRS at approximately 40Kbps. Once connected to GPRS users can be online all day for no additional charge. Users pay for the data they transfer only, costs vary by provider and plan, but expect to pay approximately 1 cent for each kb you transfer. There are applications which allow users to manage data transfers while on GPRS. Australian telecommunications providers are starting to unveil uncapped GPRS plans which will broaden the uptake of GPRS.

EDGE (Enhance Data Rates for Global Evolution)

EDGE can be introduced in two ways: (1) as a packet-switched enhancement for general packet radio services (GPRS), known as enhanced GPRS or EGPRS, and (2) as a circuit-switched data enhancement called enhanced circuit-switched data (ECSD).

EDGE is the next step in the evolution of GSM. The objective of this new technology is to increase data transmission rates and spectrum efficiency and to facilitate new applications and increased capacity for mobile use. Existing services such as GPRS and high-speed circuit switched data (HSCSD) are enhanced by offering a new physical layer. The services themselves are not modified.

EDGE is a technology that gives GSM the capacity to handle services for the third generation of mobile telephony. EDGE provides three times the data capacity of GPRS. Using EDGE, operators can handle three times more subscribers than GPRS; triple their data rate per subscriber, or add extra capacity to their voice communications. It allows consumers to connect to the Internet and send and receive data, including digital images, web pages and photographs, three times faster than possible with an ordinary GSM/GPRS network. GPRS allows data rates of 115 kbps and, theoretically, of up to 170 kbps on the physical layer. EGPRS is capable of offering data rates of 384 kbps and, theoretically, of up to 473.6 kbps.

EDGE is a method to increase the data rates on the radio link for GSM. Basically, EDGE only introduces a new modulation technique and new channel coding that can be used to transmit both packet-switched and circuit-switched voice and data services. EDGE is therefore an add-on to GPRS and cannot work alone. GPRS has a greater impact on the GSM system than EDGE has. By adding the new modulation and coding to GPRS and by making adjustment to the radio link protocols, EGPRS offers significantly higher throughput and capacity.

Bandwidth

The correct definition of bandwidth is; the “speed” at which electronic information can flow through a computer or a communications channel in a given time period. For example, the time it takes to open an image on our hard drive depends on our computer's speed (bandwidth). If the image is on the Internet, the speed of your Internet connection (your bandwidth) will determine how quickly the image can be loaded on to our computer screen.

The web hosting industry has borrowed the term bandwidth and used it to describe the amount of electronic information that passes between a web site and the Internet. A term that more accurately describes this is data transfer. The amount of data transferred from a web site to the Internet depends on the number of people visiting a web site and what kind of data they download. As the number of people visiting a web site increases so the amount of data transferred from that web site increases. In the web hosting world this would be increased the amount of "bandwidth" used by that web site.

Cost of Bandwidth

Telstra offers two different types of GPRS pricing options that effective July 2002. If users frequently download information, they may be better suited to GPRS monthly packs. For low data users, people may be better suited to the "pay-as-you-go" option, as it is described in Table 4.1.

Table 4.1 Cost of Bandwidth

Session fee	22 cents
Volume rate (per KB)	2.2 cents

A flat session fee of 22 cents is payable every time users access the service. After each 24 hours of continuous connection, as additional session fee applies. Data sent and received is charged at 2.2 cents per KB transferred. Table 4.2 below introduces the monthly packs.

Table 4.2 Monthly Packs

Monthly Subscription	$5	$15	$25	$55	$85
Included Data in Monthly Subscription	0.25 MB	1 MB	2 MB	5 MB	10 MB
Usage charges (per KB) over the included data	2 cents	1.5 cents	1.25 cents	1.1 cents	0.8 cents

Note: There are no session fees; 1024 KB = 1 MB of data; Unused included data in a month is forfeited and will not roll over for use in the next month.

4.3 Global Positioning System (GPS)

The Global Positioning System, usually called GPS, is the only fully-functional satellite navigation system. In the simplest terms, GPS is a means of determining a position anywhere on the planet by precisely measuring the distance from that location on the earth's surface to satellites orbiting Earth. Actually, GPS receivers do all the calculations. The only systems currently in existence are the United Stated Global Positioning Service (GPS) and the Russian GLONASS system, both military but made available for civil users.

The GPS system was launched by the U.S. Department of Defense and became fully operational in 1993. A great deal of the system's accuracy is based on timing. Each satellite has an on-board atomic clock that is accurate to within 1 second every 70,000 years.

All of the devices equipped with GPS receiver require signals from the satellites to determine an accurate two-dimensional position. With signals from satellites, a GPS device can also measure the elevation, providing the position in 3-D. The Wide-Area Augmentation System (WAAS), available since August 2000, increases the accuracy of GPS signals to within 2 meters (Http://gps.faa.gov/Library/waas-f-text.htm) for compatible receivers. GPS accuracy can be improved further, to about 1 cm over short distance, using techniques such as Differential GPS (DGPS).

In 2008, people in the world will experience another satellite navigation system, named GALILEO, launched by the European Union and the European Space Agency. GALILEO is a global navigation infrastructure under civil control which will consist of 30 satellites, the associated ground infrastructure and regional/local augmentations (http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm).

5. The Usage of Mobile Computer in Construction

In the middle of 1980s, the project management software was available in the market. As a result, the use of computer devices at the construction site office has become commonplace for large contractors. However, Haas et al. (2002) mentioned that although computers have been in use in the construction industry for many years, the application of handheld computer in the jobsite has been very limited so far.

The investigation of the use of mobile computing devices in construction industry was undertaken firstly in 1988 by Bell and McCullouch (1988). They were the first to assess the potential of using 1-D barcodes in construction (See Figure 5.1) for auto identification. Since 1988, the use and investigation of the barcode system in construction industry, especially for material management system and for bar-coded ID card for personal tracking, became very familiar amongst practitioners researchers. Some researchers looked at the use of 2D barcoding for facilities management in construction in an attempt to challenge the traditional centralised data storage method.

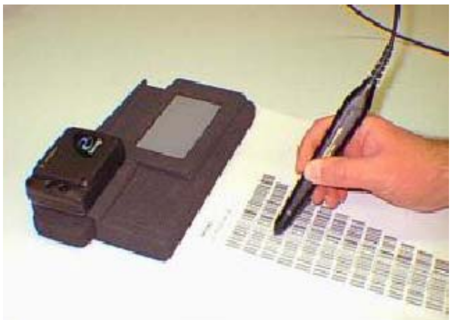

Figure 5.1 Using 1-D Barcode in Construction

In early 1990's the academic and industrial sectors investigated the use of pen-based devices, including the recently introduced Pocket PCs, for the developing applications used in field data collection (Cox et al., 2002). This research was followed in 1992 by other researchers McCullouch and Gunn (Haas et al., 2002) in terms of the investigation of the use of handheld computers in the construction jobsite. They developed a very early pen-based notebook computer for timesheet entry, materials received and daily reporting. In 1997, Bob McCullouch looked at the use of PDA's for inspection and reporting tasks similar to previous work but more aimed at construction inspection work rather than day-to-day management of construction data such as timesheets. The usage of PDA's evolved vastly during that time and by 1999, these handheld computers were being used in a construction environment, even though their applications were only restricted to inspection tasks and inventory type work.

The use of wearable computers was firstly introduced by James Garret in 1998 (Garrett et al., 1998) in order to support construction jobsites especially on bridge inspections for highways. Similar task was conducted by Danijel Rebolj on his research regarding the use of multiple mobile devices for inspection and recording tasks within highway maintenance and construction (Rebolj et al., 2000). Research from 1993 to 2000 concluded that the implantations of handheld computers in construction have focused primarily on project management, schedule management, facility inspections, and field reporting applications, and until 2002, Ward et al. looked at the application of mobile computing on-site for piling operations. That was mobile computing firstly used by active workers and not for inspection or reporting tasks. Since the last three years, the usage of mobile computing in construction has been developing in many areas with a great support of different software applications in the market. In the late 2002, Lipman (2002) introduced the application of mobile handheld computers in the field to assist construction personnel to visualise substantial 3D models.

In early 2002, Yabuki et al. (2002) proposed an on-site inspection system by using radio frequency identification (RFID) tags. Basically RFID technology has been around since the early 1920's (Dargan et al., 2004). However, In this research, Yabuki et al. (2002) proposed a new system for supporting on-site inspection of building and facilities by using and combining information technologies (IT) including RFIDs, voice input/output, wireless LAN, the internet, and knowledge management by using VoiceXML (Extensible Markup Language). This technology was suggested by Dargan et al. (2004) as an alternative system to replace traditional barcoding. RFID is a method of storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is a small object, such as an adhesive sticker, that can be attached or incorporated into a product, animal or person (See Figure 5.2). With RFID technology, no line of sight or direct contact is required between the reader and the tag.

Figure 5.2 Various Examples of RFID Tags
(Source: Dargan et al., 2004)

The application of RFID technology became very popular in 2003. Research about the application of RFID in construction was conducted by the UK's Department of Trade and Industry (DTI) in 2003. It aimed to adapt and transfer technologies for RFID, wireless communication and web applications from retail and haulage industries to the manufacturing sector supplying to the construction industry. More details applications of mobile computing devices can be seen in Appendix B.

Even there were so many applications of mobile computing in construction since the last ten years, Magdič et al. (2002) argued that there is no evidence of any systematic research in the area of mobile computing in construction. They believed there were five issues to be addressed in the applications of mobile computing in construction: (a) how does mobile computing work on-site; (b) what organisational changes are required; (c) are the common commercial mobile phone network services sufficient for mobile computing in construction; (d) how complex is the problem of integrating mobile computing into existing information systems; and (e) what educational efforts will be necessary to support the new applications.

5.1 ICT in Construction Industry

According to A Report on Information Technology (ENR, 1962) in Haas et al. (2002), one of the first applications of Information Technology (IT) in construction occurred in 1962 when the Army Corps of Engineers' Ballistic

Missile Construction Office used a computer program called TRACE (Task Report and Current Evaluation) to manage a construction project.

The need for improved project communication is a widely documented issue in the construction industry. To facilitate the management of project information and address project communication requirements, a number of ICT tools have been used with the aim to maximise benefits and reduce cost for the entire project team.

During the 1990s the international construction industry started using with increasing confidence information and communication technology (ICT) (Murray et al.). The use of e-mail became usual and web-sites were established for marketing purposes and then for one-way, followed by two-way, communication. Intranets and extranets were established to facilitate communication within companies and throughout their branches. A study from Murray et al. in the application of ICT in the African construction industry stated that an outstanding benefit of the use of web-based project sites is the minimisation of distance as a constraint on project administration.

The effectiveness of utilising ICT in a construction project could be hindered by the inability to share data in electronic form between project partners. Although it is not practical to expect compatibility between all information systems in the short term, there should be more focus on the standardisation of interfaces between the different systems. ICT tools should be able to exchange digital information with other applications/systems using appropriate data exchange standards.

Timely and accurate information is important for all project participants as it forms the basis on which decisions are made and physical progress is achieved. Waste time and cost in construction projects can be traced back to poor coordination caused by less than optimum information handling and exchange that is inadequate, insufficient, inaccurate, inappropriate, inconsistent, late or a combination of them all (Baldwin and Thorpe, 1999).

Traditionally, project Information Exchange (IE) between designers and contractors has been mainly based on paper documents. These documents come in the form of architectural and engineering drawings, specifications, and bills of quantities and materials. This practice has been far from satisfactory, with research showing that about two-third of the construction problems are being caused by inadequate communication and exchange of information and data. Research has also noted that 85% of commonly associated problems are process related, and not product related. These findings explain the growing awareness of the value of ICT to bring together the major parties in the construction process, and share project as well as industry information is a meaningful way.

The relationship between construction project participants is normally complex and involves many parameters that extend across technical, functional, business, and human dimensions. As a result, attention and focus must be given to the intensive collaboration among project participants to synchronise both the input and output of the supply chain. Undoubtedly, a key enabler to successful collaboration is the ability to communicate, and share and exchange project information is a timely and accurate manner (Smit et al., 2005).

Generally, ICT investment appraisal is more difficult than other investment decisions because ICT-induced benefits are hard to identify and quantify (Steward and Mohamed, 2004). As a consequence, more traditional investment appraisal methods such as Return on Investment (ROI), Net Present Value (NPV) or Internal Rate of Return (IRR) have been difficult to apply despite being widely understood by senior managers (Kumar, 2000). The ICT productivity paradox prompted calls for new approaches to evaluate ICT-related investment (Dos Santos and Sussman, 2000). In an attempt to provide a balanced approach to ICT performance evaluation, ICT should be evaluated across a number of perspectives (Steward and Mohamed, 2001; 2003; 2004; Mohamed and Steward, 2003).

The most common current applications of IT in construction compiled from the literature was described by Haas, et al. (2002) as follows

- Accounting;
- Building inspection;
- Daily Log Recording;
- Employee identification and access control;
- Equipment and tools tracking;
- Geographical Information System (GIS);
- Knowledge Base Systems (KBS);
- Materials management;
- Process Equipment repair;
- Speech Recognition;
- Time keeping;
- Bar Codes;
- Cost engineering;
- Document control;
- Enterprise Resource Planning;
- Equipment maintenance management;
- Global Positioning System (GPS);
- Information management systems;
- Inventory control;
- Material safety data sheets;
- Office operations;
- Purchasing;
- Quantity takeoff;
- Scheduling; and
- Three-Dimensional Data Acquisition.

The benefits of the application of IT in construction industry have been extensively researched. In Haas et al. (2002), Conlin and Retik (1997) and Williams (1994) identified some benefits such as the ability to provide instant access to relevant information, to bring together information from various sources into one concise database (integration), to provide expert knowledge in the field, to reduce costs associated with the elimination of paper-based processes, the reduction in delays, and the ability to allocate accountability when delays occur. Other significant benefits were identified by Beliveau (1996) such as providing accurate as built data both during and after construction, and giving construction workers the ability to access relevant information when they needed.

Although various construction firms have started implementing handheld computers as an application of ICT on the jobsite for gathering schedule, quality, layout, inspection, and other types of information, there have been very few real-world applications of handheld computers that may be considered an accepted way of doing business in construction. Haas et al. (2002) believed that this was because of the relative immaturity of handheld computers in construction. Unlike desktop computers, whose applications in construction have become standard practice for most contractors, the applications of handheld computers remain almost exclusively in the realm of pilot studies at innovative construction organisations or research projects at academic institutions. Furthermore, only successful applications of handheld computers reported by the hardware and software companies, as part of their marketing strategies.

Contractors can use ICTs as an enabler for integration, collaboration, knowledge management, procurement, site management and process improvement (Acar et al., 2005). However, Egbu and Botterill (2002) stated that even the implementation of ICT offers significant advantages, construction companies in general were slow to exploit their potential benefits. The building construction companies were not so keen to invest much in ICTs compared to other sectors such as manufacturing (Construction Industry Board, 1998). Researchers have identified three factors why construction industry unwilling to adopt and use ICTs (Acar et al., 2005). The first is related to cultural and psychological factors. The second deals with the satisfaction of using traditional business and tools and the third is about the fact that there is no single magic ICT solution for the whole construction market.

A study conducted by Acar et al. (2005) confirmed that there was a relationship between organisational size and attitudes towards ICT within small and medium-sized enterprises (SMEs) active in building construction. In other words, it can be said that as company size become larger, contractors use ICTSs more intensively in many field. In their research in Turkish building construction industry, Acar et al. (2005) also identified some obstacles and shortcomings to the diffusion of ICTs. The obstacles included the lack of trained staff with computer literacy and ICT knowledge and attachment to conventional ways of conducting business amongst others.

5.2 Construction Information Needs

To meet the estimated time and money budget of an executed construction project is a huge challenge to all parties that are involved into the project. Accurate information on the right time and at the right place is crucial for a successful completion of the construction project.

Information is either verbal or more likely written down in papers like word and excel documents, drawings, templates, specifications and shop drawings. On the construction site information is needed in paper form. Therefore, every information needed on the site needs to be printed out from the computer in advance and then taken to the site. This means, while many construction projects are build delivery in time, information is not available on this level.

New emerging mobile and wireless technologies like wearable computer, handheld PC and Personal Digital Assistant (PDA) are able to take over this part (Eisenblaetter, 2001). By identifying the information flow needs and by obtaining the wireless technology that meets the companies' requirements it creates a large potential to increase efficiency and effectiveness of information flow and therefore to streamline construction processes. Appendix C provides a list of information needs during the construction process.

Information needs in construction have increased as projects have become more complex and owner demands have become more challenging. By managing information more efficiently, it is hoped that value can be added to a construction project. Therefore, understanding the flow of information on a construction project and the role of the various project participants play in generating, modifying, accessing and transferring this information is vital (Haas, et al., 2002).

In construction, information is generated by many different sources and takes many different forms. The types of information in construction can be textual (specifications and contracts) or graphical (photographs or CAD drawings). Other information is form-based such as time reports, punch-lists and accident reports. In the field construction, drawings are identified as the most important types of document to transfer, therefore software for managing them is a necessary requirement for mobile computing in construction (Magdič et al., 2002). The needs of information in construction projects differ from one organisation to another. At each organisational level within a company, the amount of information needed varies, as a consequence, creating different access needs for each project participants (Coble, 1994). Moreover, Alexander et al. (1998) stated that various stakeholders in the building and construction process have different views of data that was required to satisfy their individual requirements, and a system which exhibits flexibility and a distributed approach was believed to best serve our industries needs.

The professional teams which participate in the project chain all have specific functions to carry out and the functions are made up of a number of discrete activities. Murray et al. concluded that different teams deal with similar information, therefore that information needs to be passed along the chain from team to team. This is often done in practice by paper transfer of, for example, drawings, reports, etc. Table 5.1 shows the above point for a typical project chain.

Table 5.1 Information – Role Player Matrix

Information	Role Players										
	P	**PM**	**A**	**QS**	**E**	**C**	**S**	**FM**	**LA**	**B**	**L**
Drawings	○	○	●	○	●	●	○	○	○	○	
Specifications	○	○	●	○	●	○	○	○	○		
Bills of Quantities		○	○	●	●	○	○				
Budget	○	○	○	●	○	○	○			○	○
Contracts	○	○	○	●	●	●				●	●
Planning	○	●	○	●	●	●	●		○	●	
Personnel control		●		●	○	●	●				
Materials control		●		●	○	●	●				
Equipment control		●		●	○	●	●				

Source: Murray et al.

Note:

○ – Information; ● – Initiation

P – Promoter
PM – Project Manager
A – Architect
QS – Quantity Surveyor
E – Engineers
C – Contractor
S – Sub-contractors, suppliers, etc
FM – Facilities Manager
B – Bankers
LA – Local Authorities
L – Lawyers

It can be seen in Table 5.1 that the majority of the role players require access to the majority of the project information at one time or another. It also shows that different entities often deal with similar data. Murray et al. argued that in preparation of project information, quite often firms may independently prepare similar information using different software packages. For example, Table 5.1 illustrates how both the quantity surveyor and contractor need to prepare priced bill of quantities. These professional may, however, use different and incompatible software for taking off quantities, preparing the bill and for interim and final measurement. The duplication of information may be occurred.

5.2.1 Web-based Project Sites in Project Management

One of the fastest-growing areas in the use of ICT in management is that involving the use of web-sites in project management (Murray, et al.). Based on their research, there was very similar items of information were used by most of the role players in a project cycle: the two which stand out were drawings and cost. Evidently, as the project progresses, the degree of detail increases but the basic components of the information remain the same. It is therefore suggested that the project promoter could achieve considerable savings in time and money and reduce the risk of erroneous transmission of information by taking two steps (Murray, et al.).

The first would be for the promoter or his agent the project manager, to set up a project web-site. This would contain all relevant project information. Confidential information would be password protected. The second step would be for the promoter to recommended or specify the use of compatible software on the project so that all stakeholders could easily up or download information to or from the web-site.

5.3 Flow of Information

On-site deployment of mobile computing devices in construction industry aims at improving the costly and time-consuming process of data collection and processing at the interface between physical site operations and off-site construction management activities. To be effectively applied in construction sites, the current information flow amongst project participants and the structure of data need to be analysed. These include:

- The nature of information to be collected and exchanged;
- The size and/or length of the information transmitted; and
- The frequency of the data transmitted.

5.3.1 Flow of Information within John Holland Company

Communication media such as e-mails, fax machines, teleconferences or video conferences, etc. are normally used as important means to communicate within John Holland Group and also to other project participants such as consultants, subcontractors, owners, etc. However, for any construction project located in a remote area, which telephone line is not available, a courier is used for any information exchange within construction site and site office. In a certain case, if necessary, a foreman has to travel to the site office in order to pick up an updated construction drawing. To be able to connect to the Internet, people who work in a remote area use EVDO (Evolution Data Only or Evolution Data Optimised) cards which are provided by Telstra. The card is just simply inserted to their laptops to connect to the Internet at very fast speeds.

Communication Network System

John Holland has implemented a decentralised communication network system within their company. Every project office has a fully authority to manage and control their project delivery independently under the lead of a Project Manager. This includes the ability to communicate directly to other project participants during the construction process.

Integrated Management System

The principal platform for the knowledge systems in John Holland is Lotus Notes. John Holland has built an Integrated Management System (IMS) and various knowledge databases in Lotus Notes which are generally available to all employees across the company. The key knowledge databases and elements of the IMS deal with:

- Procedures and policies;
- Business development and tendering;
- Current and completed projects;
- The skills, qualifications and experience of our employees;
- Reference materials;
- Company and client contact details;
- Plant and equipment; and
- Subcontractors and suppliers.

The IMS system in Lotus Notes also provides John Holland's correspondence, document management systems and key business process for:

- Project delivery;
- Quality management;
- Occupational health and safety;
- Management of the environment; and
- Human resources.

Project Collaboration System

John Holland, along with other companies in the Australian construction industry, has taken the decision to adopt the neutral construction industry exchange Optus inCITE (The Construction Industry Trading Exchange). Optus inCITE currently incorporates 3 web-based applications:

- Document Management;
- Tender Management; and
- Purchasing.

Optus inCITE Document Management is a collaborative tool for design management, document management, communication and project management processes. It is used to capture all information, documents, correspondence and transactions associated with a project. Optus inCITE

Tender management provides online issue and receipt of tenders, and it will manage subcontract packages from request for quotation through to the award and execution of subcontracts. It can be used alongside the Document Management application. Optus inCITE Purchasing manages the online purchasing of goods and services.

Some of the benefits which the company and its clients have enjoyed since the implementation of the Integrated Management System are:

- More integrated planning and effective control over operations;
- Management and exploitation of the company's knowledge;
- Reduction of costly wastage and duplication of resources;
- Greater understanding and effective communication of responsibilities and processes among all parties; and
- Continuous learning and improvement of our people in every aspect of our business activities.

Existing Hardware Used

Officially, desktops and laptops are the most devices used by John Holland. Some Managers are familiar with the use of PDAs for their personal needs. Handheld devices are never used during the construction process for any information exchange.

5.3.2 Flow of Information within Woods Bagot Company

The information exchange within the Woods Bagot company and amongst project participants during the construction process follows the organisational hierarchy. In other words, a centralised communication network system is implemented in this company. As an Architect company which is dealing with construction drawings, all information or data is transferred mostly in paper-form or its equivalent (ie. PDF documents). Discussion in relation to clarify construction drawings or other similar issues such as design changes, requirements and specifications changes, etc. is conducted by arranging a meeting either in the office or construction site.

Communication Network System

Woods Bagot implements a Wide Area Network system linking its many offices together. However, communication with others outside of the Woods Bagot network is still done via traditional means – telephone, fax, email or face-to-face.

Project Collaboration System

Woods Bagot does not employ any specific project collaboration system to communicate with other project participants. In a certain construction project, they may implement one of a number of 3rd party systems eg. ProjectWeb, ProjectCentre, Aconex, Optis InCite, or Buzzsaw – for example, to establish better communication with contractors, consultants, owners and other project participants.

Existing Hardware Used

Desktops or laptops are the devices most used for daily construction activities within Woods Bagot. Pocket PCs are used by a number of mobile users, but predominantly for emails, taking photographs or as normal mobile phones – there is no specific on-site software currently deployed.

5.4 Benefits

The benefits from any automation project, including mobile computing, can be classified into two categories: tangible benefits and intangible benefits. Tangible benefits can be quantified more easily than the latter variety.

The time spent on an activity in the construction industry can be divided into three major categories: direct work, support work and idle time (Oglesby et al., 1989). Direct work related to any time spent on work that contributes directly to the project value, such as pouring concrete and painting external wall, etc. Support work can be identified as time spent on an activity which is necessary to undertake to support the direct work, but do not actually put work in place such as interpreting drawings, moving of materials, etc. Whereas idle time includes any other time spent on the project such as waiting for materials, information and instructions. The use of handheld computers in the construction sites does not actually put work in place. In other words, handheld computers, are considered information tools, may indirectly increase the amount of direct work on a project by directly decreasing the amount of support work and idle time (Haas et al., 2002). This is statement is clearly shown in Figure 5.3.

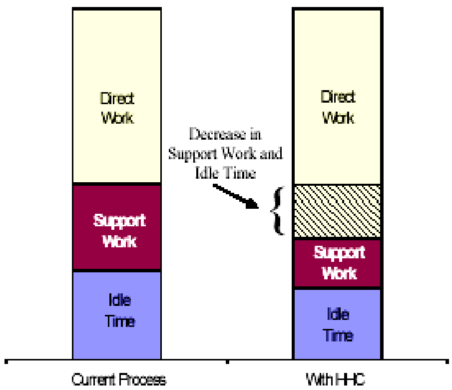

Figure 5.3 Benefits of Handheld Computers (Source: Haas et al., 2002)

In 1999, Alemany (1999) conducted a survey of almost 200 construction foremen in USA and showed that personnel who used computers at work saved time on paperwork and could spent more time on supervision. Figure 5.4 shows the time spent by a Foreman during the construction process.

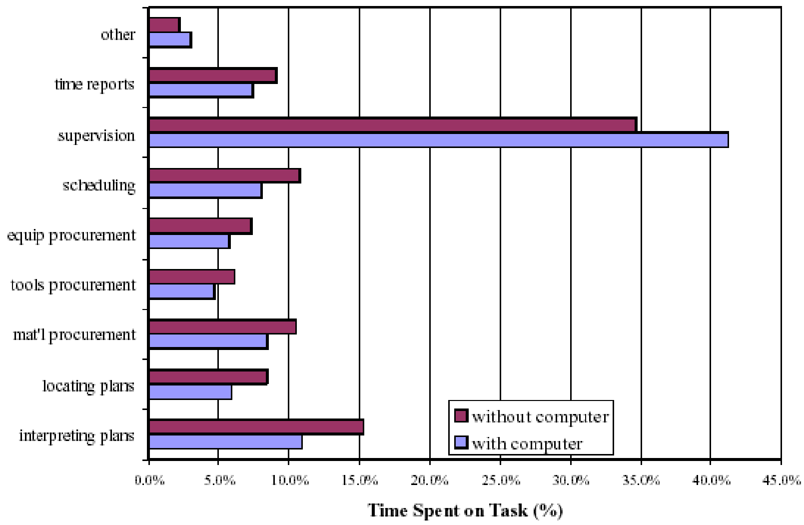

Figure 5.4 Time spent by a Foreman in the jobsite (Source: Alemany, 1999)

Similar result was found by Mc Cullouch and Gunn (1993) on their survey in relation to potential time savings by supervisors during the construction processes. They found that supervisors spent between 36% and 50% of their time on paperwork related to employee time keeping and material management functions. Based on the two surveys above they suggested that by using handheld computers effectively in the field for employee time keeping and materials management alone could enable foremen to spend more of their time supervising. Consequently, this could have positive impacts on productivity and quality. These arguments were supported by Haas et al. (2002) as they believed that by providing construction workers with handheld computers, it could help them managing construction tools and equipment, materials, sending request for information, and also accessing relevant schedule information. These could potentially allow them to spend more time on direct work and less idle time waiting for answer or needed tools and materials.

In early 2001, Magdič et al. (2002) conducted a research into a road construction project in order to explore the potential of mobile computing for construction industry. They mentioned that the efficiency of information exchange in the construction sites could be improved significantly by using current mobile computing: unmodified, currently available PDA, mobile phones and web services (See Figure 5.5). However, during the construction process, they found some problems related to the use of such devices. The available PDAs were not suitable under stress conditions required in construction sites such as dust, strong light, rain, handling by workers (rugged). Other problems related to data input, screen size (either too small for good information overview, or too large to fit in a pocket). Although the company has a relatively good level of IT use, most documents circulating on site were in printed form and have a limited data structured, which made them unsuitable for direct use in the mobile computing system. Document management system was found to be another serious problem. The mobile computing system is needed to be redesigned and improved to allow all information to be transferred automatically to right person at the right time as well leading to attain a higher degree of information integration and a higher efficiency of information flow.

Figure 5.5 Application of PDA in Construction Sites

Other benefits of using handheld computer were recognised by Cox et al. (2002) They argued that automation of the field data collection process could help eliminate double entry of recorded data, which in turn minimised errors. The authors also mentioned that the benefits included the reduction of paperwork, automatic generation of reports, and faster distribution of electronics data leading to savings construction costs through decreased delays and reduction in labour time.

A recent study conducted by Ward et al (2004) proved that a significant benefit of the implementation of a mobile site level data collection system for piling works has been achieved. The cost benefit analysis indicated a 75% reduction in the cost of remedial work on their research project. Each user was equipped with a touch-screen Windows CE tablet computer (See Figure 5.6.). This enabled the users to gain access to the server-side database over the wireless network, effectively providing full desktop capability to the users.

Figure 5.6 Tablet Computer Used On-sites

The benefits of using mobile computing in construction industry were supported as well by a recent study conducted by Jadid and Idress (2005). They mentioned that site inspection and project status reporting was considered as a high value mobile application by construction engineers because it reduced the number of site visits by supervising engineers by half or greater. Moreover, they said that while construction industry has been slow in adopting mobile computing and automation in the field, things were changing quite fast now, since low-cost handheld devices were available and several construction automation applications have been developed by vendors.

Jadid and Idress (2005) believed about the fact that the locations of construction sites frequently change which could cause a delay in collecting data from the field, and therefore produced a great need and importance for mobile computing. The field client not only collects data, but it also provided information to the progress engineer. In Jadid and Idress (2005), the annual report by Daito (2000) mentioned four main benefits of the system such as:

- It eliminated redundancy in project task operations;
- Reduced the response waiting time;
- Greatly limits revision of job tasks; and
- Enabled access to new construction standards.

In general, the following benefits have also been identified in the literature (Newel, 1994; Williams, 1994; dela Garza and Howitt, 1998):

- One-time handling of data in the field.
- Elimination of illogical data entry.
- Completeness of entered data.
- Selecting data from predetermined lists speeds up data entry and standardises the results.
- Data integrity was improved by the elimination of sensitive paper-based recording of data.
- Less storage space for documents was needed since paper documents were not necessary.

- Fewer hard copies of relevant field information were required since they can be accessed on the computer.
- Information might be exchanged wirelessly.
- Updating the HHC's database and recharging its battery was simplified through the use of docking stations ("cradles").
- Electronic measurement instruments could be incorporated into HHC's (digital tape measures, GPS, etc.).
- Field computations were simplified through the use of special software and built-in calculators.
- The HHC could also capture sketches and signatures.
- Users could also view maps and CAD files.
- A help knowledge-base could also be incorporated into HHC software to aid field personnel in solving problems and understanding their tasks better.

5.5 Barriers and Shortcomings

Even significant benefits of using mobile computing have been identified by some researchers, several barriers and shortcomings can be affected the application of mobile computing in the construction sites.

Haas et al. (2002) introduced that the barriers of using handheld computer in construction were a result of two factors: (1) the handheld technology's limitations and (2) the characteristics of construction industry. The technology's limitation included the features of the handheld computer such as form factor, input interface, operating system; and the specifications of the handheld computer. The construction industry barriers consist of the physical jobsite conditions (such as temperature, humidity, dust, etc) as well as organisational issues (such as the familiarity of the construction personnel with handheld computers). Another problem identified by Haas et al. (2002) was related to the reliability of the wireless network connection. During the case study, Haas et al. (2002) experienced frequent interruptions in the network connection that either caused by a weak radio signal or by interference.

Implementation of Digital Construction (2003) found significant barriers of using ICT (including mobile computers) in the building industry. The barriers were grouped into four categories such as technological barriers; barriers relating to overall economy (financial); organisational/cultural barriers; and legal barriers. These barriers were found in connection both with internal company use of ICT and with data and information interchange. However, they assumed different specific forms in the two areas. The fourth type, the legal barriers, was most relevant to data interchange between companies. This argument was supported by another researcher (Beyh and Kagioglou, 2004) who experienced some significant barriers in the implementation of IP telephony in the UK construction industry.

5.5.1 Technical Barriers

The impact of successful, widespread adoption of advanced ICTs in the construction industry could be very significant. However, at the present time there are still numerous reasons due to which, ICT applications have not yet reached their potential in the construction sector. One impediment for many people and firms is for example “the fear of technology” as 10-15% of the population will retire out of the industry before they embrace technology (Beyh and Kagioglou, 2004). Other technical barriers such as the internet bandwidth requirements, voice transmission delays, lack of standardisation of formats and other data deficiencies in data discipline (file formats, data formats, communications standards, etc.), and lack of suitable users' devices are essential concerns for decision makers for considering its implementation.

5.5.2 Financial Barriers

Investing in new communications technologies and systems should have the potential to allow an adequate and rapid Return on Investment (ROI). Construction firms may not be willing to undertake new investments of the kind before taking full advantage of their existing systems. The cost of technology is believed to be an important barrier to technological innovation that a number of organisations point to when explaining their reluctance to implement wireless solutions, even though they recognise the value of their advanced applications (Stark, 2002).

Love et al. (2001) and Beyh and Kagioglou (2004a) argued that construction industry business relied on cash flow availability and thus, firms could not invest in technologies that would not bring about immediate benefits. The financial barriers they were referring to, include:

- The cost of system acquisition, requirements, and maintenance,
- Investment risk,
- Financial power and amount of available credit,
- Cost of training and end-sure education,
- Losses in productivity, and
- Market uncertainty.

Beyh and Kagioglou (2004) concluded their research as construction firms could be reluctant to the integration of new technology because it was perceived as a new communication paradigm that would need considerable investments, but might offer the same services similar to those already found in the traditional telecommunication systems without further competitive advantages.

5.5.3 Cultural Barriers

The cultural issues in the construction industry as a major part of influence on the development and adoption of new technologies have been well reported in the last few years (Beyh and Kagioglou, 2004). Moreover, they emphasised on the difficulties in the construction industry of adopting new ICT applications by a resistance for the management to change, and a belief that the industry was doing well without it. Therefore it may be debated that in order to be successful, a migration to, and adoption of new technologies must strongly consider looking at consequences where an attempt to change the users' culture is likely to take place. Because change is always asking people to do something different and adopt a different belief or attitude, it would be therefore necessary to analyse the organisation, the employees and their readiness for such a change prior to initiate it. Cultural issues in the construction sector could therefore affect the decision to integrate new technologies.

5.5.4 Organisational Barriers

Anderson (1992) noted that the construction industry and its employees were being impacted by technology. The industry is affected by the use of computers; fax machine, telecommunications, new products, equipment, and robotics. Demographics clearly indicated the lack of technological skills in the upcoming work force. The educational level of employees would need to be increased to meet these challenges. Current employees would need training, retraining, and cross training to keep abreast of new technology. Bennet and Durkin (2000) argued that organisational change significantly influences employee commitment to the organisation especially when the perceived values of the organisation have changed.

5.5.5 Legal Barriers

As has mentioned before, the legal barriers are most relevant to data interchange between companies. The barriers will be arising from the fact that the transition from paper-borne to digitalised information requires a parallel development of the legal system such as digital signature and transparent judicial usage).

5.6 Mobile Computing Devices Limitations

Kondratova (2004) believed that smart devices such as Smart phone, Pocket PC, PDA, hybrid devices (such as phone-enabled PDAs or Pocket PCs), and wearable computers will become powerful enough to replace laptop computers in the field and will be widely used for real time communication, of construction project information, to project repositories or between project participants. However, Kondratova (2004) said that the potential of using mobile, handheld devices in the field for real time communication was limited by their technologies' limitations. Haas et al. (2002) also argued that handheld computers were bound by several key technologies that limit their functionality under certain conditions. These limitations involve handheld features such as screen size, screen visibility, processing capability, and input method. For examples, a small screen size and the need to use a pen to enter data and commands present a great inconvenience for field users – especially if their hands are busy using other equipment, or instruments. Tables 5.2 and 5.3 present some examples of construction tasks that are not suited and suited for handheld computers, respectively (Haas et al., 2002).

Table 5.2 Tasks Not Suited for Handheld Computers

No	Task description	Example
1	Tasks that require computer processing power comparable to that found in desktop computers	Editing a 3-D construction drawings
2	Tasks that require a “big picture” view of document	Viewing a drawing or a network schedule
3	Tasks that require a constant (always on) connection to a computer network	Working with data store on a mainframe
4	Tasks that require a considerable amount of manual data entry (or writing)	Writing a progress report
5	Tasks that are likely to be performed mostly in direct day light, or under very bright artificial lighting	Working with no roof overhead during the day
6	Tasks that actually put work in place	Nailing, cutting, digging, and etc.

Table 5.3 Tasks suited for Handheld Computers

No	Task description	Example
1	Tasks that require access to large amounts of text information	Reading standard/specs, building codes, knowledge base, etc.
2	Tasks that require viewing a small detail of a document	Viewing a close-up of a steel beam construction diagram
3	Tasks that require the entry of binary data	Answering yes/no questions, checking-off items on punch lists, etc.
4	Tasks that require the entry of data into a form	Filling-in a safety or equipment usage report
5	Tasks that require instant transfer of small amount of information to and from a network	Sending and receiving e-mails, looking up the latest material procurement information

6. Conclusions

Mobile computing is becoming more desirable and prevalent on construction sites. It is an important and evolving technology. Using mobile computing devices mobile personnel are able to communicate effectively and interact with the fixed organizational information system while remaining unconstrained by physical location. A mobile computing device may be implemented using many combinations of hardware, software, and communications technologies, and also with a suitable wireless capability can reduce travel costs, increase operative efficiency, and speed data transfer. The technologies, of course, must be carefully selected and the applications designed to achieve the business needs required from the overall organizational information system.

On-site construction operations require complex coordination between a number of activities. Effective construction processes depend on good synchronization of materials delivery, movement of equipment and construction tasks. Coordination tasks are often complicated by schedule pressure and productivity demands, worker fatigue, data loss during information exchange, misunderstandings because of poorly defined information, and iterative negotiation when unanticipated events occurs. Without appropriate computing support including the use of web-based project sites this may increase the difficulty of problem solving.

The commercially available mobile devices already offer abundant functionality and processing speed, however, to be applied in construction sites, the devices should meet certain stress conditions like dust, strong light, and rain. The screen size is another issue to consider choosing a mobile device. The screen should be big enough to view information and also should be small enough to be carried around.

Mobile computing has many benefits that can improve construction processes. The most significant benefit is the devices' ability to provide construction workers with real-time access to relevant information at the construction sites, and to send real-time information back from sites to the appropriate decision makers. In addition, with the appropriate use of a mobile device on-site, the accuracy of the information being exchanged can be improved.

However, it should be mentioned as well that implementation of new technologies is always accompanied by many challenges. Important issues related to barriers of using mobile computing technologies on-site need to be considered.

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www.symbian.com/phones/

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www.geneg.com

Appendix A: Software Available on Market

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
1	Carlson Software	www.carlsonsw.com	For Construction: Carlson Takeoff	Construction quantity takeoff.	Windows XP Prof/XP Home/2000/NT 4.0	PC/laptop	$9000
			For Construction: Carlson Field	Collecting construction data	Windows XP Prof/XP Home/2000/NT 4.0	PC/laptop	$2995
			For Mining: Carlson SurvCADD Mining	Designing and Mapping in mining industry.	Windows CE	PC/laptop/ handheld	$1000-$1500
			For Mining:Carlson SurvCADD Advanced Mining	Designing and Mapping in mining industry.	Windows CE	PC/laptop	$5000-$9000
2	Computer Methods International Corp.	www.cmic.ca	CMiC Enterprise	Financials, Projects, Human Capital Management, and Asset Management			
			CMiC Project Management	Cost and Budget Management, Bid and Procurement Management, Document Management, Site Management and Collaboration Manager.			
			CMiC Integration	Interchange, Imaging, Mobile, Business Intelligence and Workflow.			

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
3	Cheetah Advanced Technologies, Inc	www.cheetahware.com	StreetSmart (For heavy construction)	Construction Management Solutions; Equipment Operations; Financial and Materials Management.			
4	Comware	www.comwareptyltd.com.au	INFIELD software systems	Barcode, Auto ID, Data collection, Mobile computing and Labelling system		Pen, Handheld PC and PDA	
5	Construction Applications Software, INC.	www.capscentral.com.index.htm	CAPS construction software	Construction Estimating, Construction Accounting and Project Management	Windows (all versions), Linux and Terminal Services.	Desktop and handheld.	
6	Corecon Technologies, Inc	www.corecon.com	CORECON 4.0	Project Estimating, Project Management, Job Cost Control, Project Collaboration, and Accounting Integration.	Hosted Solution	Desktop	
7	Dexter+Chaney	www.dexterchaney.com	Forefront Project Management Software	Workflow Management.	Palm OS version 2.0 or later.	Specific Handheld devices.	
			Document Imaging Software	Documentation Management	Palm OS version 2.0 or later.	Specific Handheld devices.	
			Human Resources Software	Employee Management.	Palm OS version 2.0 or later.	Specific Handheld devices.	

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
8	Emerging Solutions, Inc	www.constructware.com	Constructware ASP	Internet-based Project Management, Collaboration and Design Management	Windows 95/NT	PC	
			Constructware for Sub-Contractors	Project Management	Windows 98/ME/NT 4.0/2000 Pro/XP Pro	PC	
9	Fingertip Solutions, Inc	www.fingertipsolutions.net	Construction Management Professional 2.5	Project Management, Cost and Scheduling Control.			
10	Handheld Systems Ltd	www.pocket-survey.net	PocketSurvey.	Surveying Systems.	Windows 98 or above	Handheld/ iPAC Pocket 7PC	
11	IBM Corporation	www.ibm.com	Lotus Notes 7.x	Notes for Messaging and Notes for Collaboration.	Windows 95/98/NT/2000/ Professional/XP; Macintosh OS X 10.1x and 10.2x, 10.3.	PC and Handheld	AUD 171.09-237.60
12	I-man	www.i-man.com.au	Build*Central.*	Scheduling & Call Forwarding; Customer Communications; Contractor Management.		PC and Handheld devices	
			OHS*Track.*	Risk Management; Incident Reporting; Training Registers; Compliance; JSA; SWM; SOP.		PC and Handheld.	
			Service*Track* .	Timesheets; Resource Management; Invoicing.		PC and Handheld devices	

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
13	Imagemation Pty Ltd	www.imagemation.com.au	ClickHome.	Project Management/Integration; Planning-Scheduling.	Windows.net/ 98/XP/	Desktop/Pocket PC	$4000-6000/supervisor
			Microsoft BizTalk.	Integrating Business Processes.			
14	Informative Graphics Corporation	www.infograph.com	ProjectDox	Project Collaboration.	Windows 2000, XP, 2003	Desktop	
			MYRIAD	3D/2D view and markup.	Windows 2000, XP, 2003	Desktop	
			ModelPress	3D CAD Viewer & Secure 3DF Publishing	Windows 2000, XP, 2003	Desktop	
15	Maxwell Management Suite	www.maxwellmanagementsuite.com	Maxwell Management Suite Software	Job Cost Accounting; Service Management and Dispatch; Project Management Construction; HVAC Service; Construction Accounting.		PC and Handheld devices.	

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
16	Miridian Systems	www.meridiansystems.com	Proliance (Plan-Bild-Operate)	Project Portfolio Management; Facilities Management; Business Intelligence; Business Process Management.		PC	
			Prolog Application Suite	Project Management Control		PC and PDA	
			ProjectTalk (Subscribe and access via the Internet)	Project Management		PC	$324-$1536/year or $30-$160/month
17	MobileDataforce	www.mobiledataforce.com	PointSync	Field Data Capture	Windows 2000, Windows XP, Windows 2003	Handheld	
			Intercue		Windows 2000, Windows XP, Windows 2003	Handheld	
18	Myoporum Pty Ltd	www. mobiledatacollector.com	Mobile Data Collector (MDC)	Create data collection form that can be accessed by internet enabled mobile devices		Handheld	
19	National Schedule Masters	www.schedulemasters.com	TracTime.	Construction Scheduling Home Building.	Windows 98/NT/CE/2000/XP	PC/Laptops/ Handheld	

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
20	Northwest Builders Networks, Inc	www.nwbuildnet.com	QuickGantt Project Management	Construction Project Management	Windows 98/2000/nt 4.0/XP	PC	$99.95-$2092.
			WinEst LT. 4.5 Professional	Construction Estimation	Windows 95/98	PC	$299
21	Primavera System Inc	www.primavera.com	Primavera Engineering & Construction.	Project Planning and Control.	Windows 98 SE, NT 4.0 Workstation SP6a, 2000 Professional SP4, XP Professional SP1.	Pocket PC 2000 and Palm OS 5.0	
			Primavera Professional.	Contract, Document and Cost Control.			
			Primavera Contractor.	Planning and Scheduling for Construction Industry.			$495-$794
			Primavera Project Planner.	Project Management.	Windows 95/98/ME/NT/2000/XP		
			PrimeContract.	E-business management.			
			Suretrack Project Manager.	Project Management.			$499-$798
22	Software Innovation, Inc	www.softinn.com	Coreworx	Construction Project Management			
23	Turtle Creek	www.turtlesoft.com	Goldenseal	Project and Business Management, Accounting, and Cost Estimating.	Macintosh 7.0 or newer/Mac OS X; Windows 98/NT/2000/ ME/XP/XP Pro.	PC	$295-$1495

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
24	UDA Technologies, Inc.	www.uniteddesign.com	Uda Construction Office 2004 Professional (Project management for Construction Professional)	Construction Management; Estimating and Productivity.	Windows XP/2000/NT/ ME/98/ Macintosh OS 9.1 or higher.	PC	$499.95
			Construction Office Builder 2004 (For residential builders)	Construction Management; Estimating and Productivity.	As above.	PC	$319,80
			Construction Office 2004 Design-Build	Design-Build Professional.	As above.	PC	$399.95
			Construction Office 2004 Construction Management.	Construction Management;.	As above.	PC	$399.95
			Construction Office 2004 Architect	Residential Architects and Designers	As above.	PC	$399.95
			Construction Office 2004 Light Commercial	For Light Commercial Construction	As above.	PC	$399.95
			Construction Office 2004 Mobile Integration.	Construction Management; Estimating and Productivity.	As above.	Pocket PC	$299.95

Appendix A: Software Available on Market (Continued)

No	Company name	Web-site	Product name	Usage	O/S Platform	Hardware	Price
25	Virtual Boss, Inc	www.virtualboss.net	VirtualBoss 3.68	Construction Scheduling and Project Management	Windows 95/98/ME/NT/2000/ XP/CE/Tablet XP	PC; Pocket PC; Palm Pilot	$395 and $69.95 for Pocket PC.
26	Visiarc System	www.visiarc.com	Visiarc Wireless viewer/Webviewer Pro 2004	PDFs; AutoCAD Drawings; Maps.	Windows 98/ME/NT/2000/XP/ Unix/Linux/Mac OS X.	Smartphones; PDAs; ruggedised h/hs; tablet PC; laptops and any workstation.	
			Visiarc Webviewer OEM 2004	PDFs; AutoCAD Drawings; Maps.	Windows 98/ME/NT/2000/XP/ Unix/Linux/Mac OS X	Smartphones; PDAs; ruggedised handhelds; tablet PC; laptops and any workstation.	
27	Xora, Inc	www.xora.com	Xora GPS TimeTrack	Tracking employees' timesheets, jobs and locations.	Java	PC and specific mobile devices (Nextel and Blackberry)	From $11.99 per phone per month.

Appendix B: Mobile Computing Devices Applications

Mobile Computing

Year	Applications	Researchers
1993	Pen-based notebook computer for timesheet entry, material received and daily reporting.	Bob McCullouch
1996	Gator communicator (tablet computer, digital camera, GPS and barcode reader) was used for construction supervision.	John Alexander
1997	PDAs was used for construction inspection and reporting tasks.	Bob McCullouch
1997	Developed a global mobile wireless communication system with the aim to support all business units in the construction and mining industries.	Carnegie Mellon
1999	PDAs were used in construction environments for inspection tasks and inventory type works	G. Navarette
2001	PDAs were implemented for document access from construction sites.	Karin Eisenblaetter
2002	Mobile computing in the jobsites for piling operations.	Michael Ward
2002	Handheld computers were implemented in the construction industry for punchlisting, materials tracking, Materials Safety Data Sheet (MSDS) access, drawing access, RFI's and quantity surveying.	Karmel Saidi, Carl Haas, Nicole Balli (Carl Haas, Richard Tucker, Kamel Saidi, Nicole Balli).
2002	Virtual Reality Modelling Language (VRML) on mobile handheld computers (Pocket PC) for viewing 3D structural steelwork.	Robert R. Lipman
2002	Usage of Pocket PC for automating field data collection process. The applications included data recording, processing and distributing.	Sean Cox, Jose Perdomo, Walid Thabet
2003	Usage of PDAs, mobile phones and other existing wireless networks and internet services to support on-site document exchange.	Ales Magdic, Danijel Rebolj, Natasa Suman
2003	A Pocket PC PPT-2800 was implemented in the Gas and Oil Construction Industry for automating the tracking process.	Ramzi Labban

Mobile Computing (Continued)

Year	Applications	Researchers
2003	Handheld computers were used in recording building defects at a construction sites electronically, communicating that information to a central computer system at head office and making that information available to other project participants.	Pearce Group (Priority Defect Management)
2004	Field Force Automation (FFA) applications in real-time support of orders, scheduling, supervising and reporting in the construction field.	Thomas Olofsson and Mats Emborg
2004	Usage of ENVIT Field Notebook Data Collection System for hydraulics and water quality field measurements	Vivoni, E.R.; Camilli, R.; Rodriquez, M.A.; Sheehan, D.D.; and Entekhabi, D
2005	Application of PDA on construction management for daily inspection, checklist and reference, position check and progress monitoring systems.	Kenji Kimoto, Kazuyoshi Endo, Satoru Iwashita, Mitsuhiro Fujiwara
2005	Implementing mobile computing for daily data collections and reports from the real construction site. This included the use of WiFi or blue tooth technology with handheld computers for data transmissions at the construction sites.	M.N. Jadid and M.N. Idress

Auto Identification and Barcoding

Year	Applications	Researchers
1988	1D barcodes in construction.	Bell and McCullouch
1990	Barcodes on tracking plant items for maintenance.	Leonard Berhold
1994	Barcoding system was used for locating and management of precast concrete beam.	Tony Thorpe
1996	Usage of barcoded ID cards for personnel tracking.	Escheverry
1996	Usage of 2D barcoding system for facilities management in relation to enhance data storage method.	Ed Finch
1996-1988	Usage of Itag SYSTEM at Bovis Lend Lease for materials receipt on sites.	Finch and Marsh

Auto Identification and Barcoding (Continued)

2002	PDA and RFID tags were used into structural members of a building for inspection activities.	Nobuyoshi Yabuki
2002	Barcode technique was used to facilitate effective management of construction materials in order to reduce construction waste.	Zhen Chen, Heng Li and Conrad Wong
2003	RFID was used by Bechtel company for tracking materials in the construction jobsites. RFID systems were used as well for materials management process, concrete placement, tracking tools and equipments.	Mike Schneider
2003	A built-in barcode scanner in a Pocket PC was used for managing gas and oil pipes in the remote area.	Ramzi Labban
2005	"Part and Packets Unification System" by using RFID was implemented in the construction process.	Junichi Yagi, Eiji Arai, Tatsuo Arai

Mobile Ubiquitous Devices

Year	Applications	Researchers
1996	Usage of a digital hard hat with a camera mounted display which could be connected to a PDA touch screen.	Tony Thorpe and Liang Liu
1998	Usage of wearable computer with a heads-up display, tablet computer wearable computer pack and voice activated software for bridge inspection and highways.	James Garrett
2000	Usage of multiple devices without voice activation (wearable computers) for inspection and recording tasks within highway maintenance and construction.	Danijel Rebolj
2000	Wearable computers and Palm PC were used to perform the building inspection, primarily for plumbing and electrical systems.	Scott Fuller, Zhihui Ding and Anoop Sattineni
2003	Developed a digital hard hat which incorporates with a camera and GPRS communications from transmitting images from sites.	Who Hup Construction, QinetiQ and the Singapore Building Construction Agency

Appendix C: Jobsite Information Needs

Request for information	Materials management	Equipment management	Cost management	Schedule, tools and methods	Jobsite record keeping	Safety	QA/QC
Design intent and clarification	Access to material management	Equipment location	Budget	Schedule updates	Recording timesheets	Accidents reporting	Initiate inspections
Subcontractor information	Material location	Fuel monitoring	Material cost accounting	Delay recording	Progress reporting	Reporting violations	Report QA/QC problems
Contract specifications	Material order status	Request equipment to site	Equipment cost accounting	As-built records	Exception reporting		Report inspection results
Contract drawings	Request materials to site		Cost variations	Productivity information	Visitor's log		Rework recording
Work package information	Place material orders						Test results
Tools and methods							Revisions recording
Implementation problems							
Supplier information							
Health-Safety regulations							

Source: Adapted from Eisenblatter, K. (2001)

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