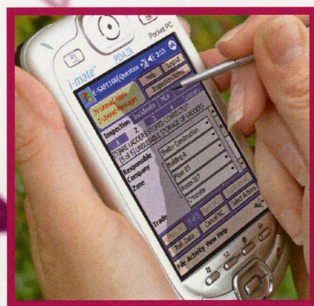

Application of Mobile IT in Construction

Sarah Louise Bowden

CICE

Loughborough University

Application of Mobile IT in Construction

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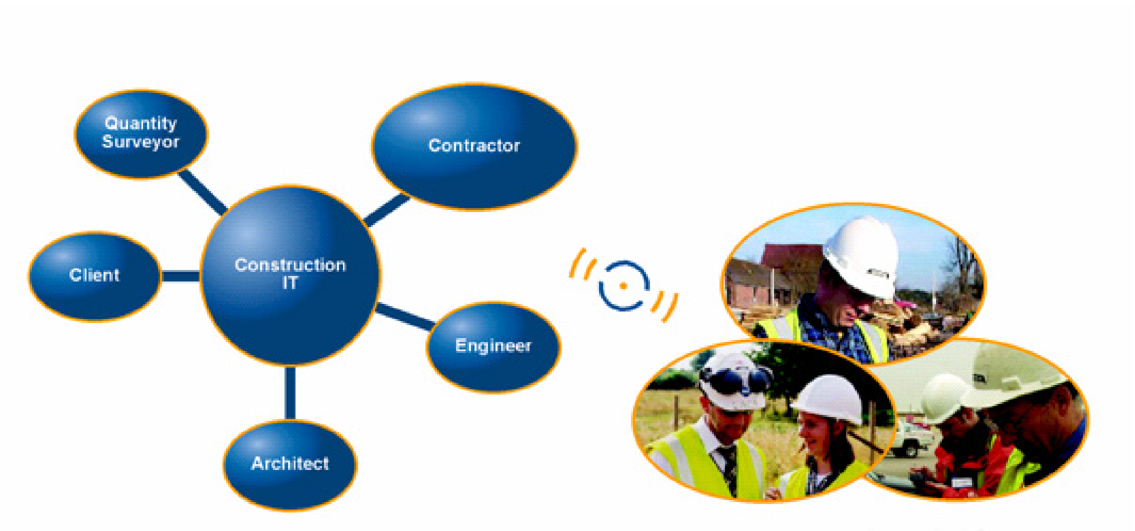

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APPLICATION OF MOBILE IT IN CONSTRUCTION

By
Sarah Louise Bowden

A dissertation thesis submitted in partial fulfilment of the requirements for the award of the Engineering Doctorate (EngD) degree, at Loughborough University

September 2005

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During this study I have benefited greatly both from those mentioned above and Prof. Chimay Anumba, Prof. Andrew Baldwin and Ir Alex Dorr. Their continual guidance, support and encouragement have made completing this doctorate not only educational and enlightening but fun too.

I am also in debt to the members of the COMIT community and the Arup staff that have shared their valuable knowledge and time with me. Without their input this research would not have been as representative of the industrial context.

A final thanks goes to my family, friends and fellow researchers and especially to my husband, John, whose continual support and encouragement reassured me that I had done the right thing.

ABSTRACT

In recent years, the construction industry has been compelled to explore all possible options for improving the delivery of their products and services. Clients are now expecting a better service and projects that meet their requirements more closely. This has challenged the industry to become more efficient, integrated and more attractive, with benefits for its potential workforce and for society as a whole.

Information and communication technologies (ICT) are an enabler to facilitate the improvements required for modernisation. However, due to the geographically dispersed and nomadic nature of the construction industry's workforce, many people are prevented from efficiently and effectively using the ICT tools adopted to date. Mobile technologies providing the 'last mile' connection to the point-of activity could be the missing link to help address the ongoing drive for process improvement. Although this has been a well-researched area, several barriers to mainstream adoption still exist: including a perceived lack of suitable devices; a perceived lack of computer literacy; and the perceived high cost.

Through extensive industry involvement, this research has taken the theoretical idea that mobile IT use in the construction industry would be beneficial, a step further; demonstrating by means of a state of the art assessment, usability trials, case studies and demonstration projects that the barriers to mainstream adoption can be overcome. The findings of this work have been presented in four peer-reviewed papers. An ongoing dissemination programme is expected to encourage further adoption.

KEY WORDS

Mobile technologies, PDA, case studies, site information technology, construction industry

PREFACE

This thesis represents the research conducted between 2000 and 2005 to fulfil the requirements of an Engineering Doctorate (EngD) at the Centre for Innovative and Collaborative Engineering (CICE), Loughborough University, UK. The research was undertaken within an industrial context and sponsored by Arup, a leading international engineering consultancy.

The essence of the Engineering Doctorate is to solve one or more significant and challenging engineering problems within an industrial context that can be shown to be of benefit not only to the sponsoring company but also to the wider construction industry.

The EngD is examined on the basis of a discourse supported by publications or technical reports. This discourse is supported by two journal papers and two conference papers. The main body of the thesis allows the reader to gain an overview of the work undertaken, while more specific aspects of the research can be found in the papers presented in the appendices at the back of the thesis. These papers are an integral part of, and should be read when referenced in conjunction with, the thesis.

ACRONYMS / ABBREVIATIONS

Auto-ID	Auto-Identification
CICE	Centre for Innovative and Collaborative Engineering
DTI	Department of Trade and Industry
EngD	Engineering Doctorate
DECT	Digital Enhanced Cordless Telecommunications
GIS	Geographical Information Systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global Systems for Mobile Communications
HCI	Human Computer Interaction
ICT	Information and Communication Technologies
IS	Information Systems
ISDN	Integrated Services Digital Network
IT	Information Technology
PDA	Personal Digital Assistant
PIM	Personal Information Management
ROI	Return on Investment
UK	United Kingdom
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network

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LIST OF PAPERS

The following papers have been produced in the course of the research undertaken for the Engineering Doctorate. Papers labelled one to four are included in the appendices and are submitted in partial fulfilment of the award requirements.

PAPER 1

Bowden, S. and Thorpe, A. (2002). Mobile communications for on-site collaboration, *Proceedings of ICE, Civil Engineering*, 150 (November 2002), paper 12989, pp 38-44.

PAPER 2

Bowden, S.L., Dorr, A., Thorpe, A. and Anumba, C.J. (2005). Making the case for mobile IT, *Proceedings of the International Conference on Computing in Civil Engineering "Dare to Think Outside the Box; Push the Envelope; and Present the Future in Computing in Civil Engineering"*. Cancun, Mexico. July 12-15, 2005. Available on CD.

PAPER 3

Bowden, S.L., Dorr, A., Thorpe, A. and Anumba, C.J. (2004). Mapping site processes for the introduction of mobile IT, *Proceedings of the 5th European Conference on Product and Process Modelling in the Building and Construction Industry - ECPPM 2004*. Istanbul, Turkey. September 8-11, 2004, pp 491-498.

PAPER 4

Bowden, S.L., Dorr, A., Thorpe, A. and Anumba, C.J. (in press). Mobile IT support for construction process improvement, *Automation in Construction*.

ADDITIONAL PAPERS (NOT INCLUDED IN THESIS)

Bowden, S.L., Thorpe, A. and Baldwin, A. (2003). Usability testing of hand held computing on a construction site, *'Construction IT, Bridging the Distance' the Proceedings of the CIB W78 Conference*, Auckland, New Zealand, April 23-25 2003. ISBM 0-908-689-71-3.

Sommerville, J., Craig, N. and Bowden, S.L. (2004). The standardisation of construction snagging, *Structural Survey*, 22 (5) pp 251-258.

May, A., Mitchell, V., Bowden, S. and Thorpe, T. (2005). Opportunities and Challenges for Location Aware Computing in the Construction Industry, *7th International Conference on Human Computer Interaction with Mobile Devices and Services*. Salzburg, Austria, September 19-22 2005.

1 BACKGROUND TO THE RESEARCH

1.1 INTRODUCTION

This chapter sets out the background to the research undertaken to fulfil the requirements for the award of an Engineering Doctorate (EngD) of Loughborough University. It provides an introduction to the general subject domain, identifies the aim and objectives, justifies the need for the research detailed within this thesis and sets it within an industrial context. The structure of the thesis is presented to provide clarity and direction to the reader and a synopsis is provided of each of the published papers that should be read in conjunction with the discourse (Appendices 1 - 4).

1.2 DRIVERS FOR MOBILE IT USE IN CONSTRUCTION

1.2.1 KEY ISSUES FACING 21ST CENTURY CONSTRUCTION

There have been many studies which aimed to identify the drivers, arising from social, technological, economic, environmental and political trends, which will influence the construction industry in the next twenty years. Flanagan (2004) consolidates these into nine key drivers:

- urbanisation, growth of cities, and transportation;
- ageing population;
- rapid technological and organisational change;
- environmental and climate change;
- shift from public to private;
- the knowledge economy and information overload;
- technologies for tomorrow;
- people, safety and health; and
- vulnerability, security, corruption and crime.

These drivers, together with global economic competition, have compelled many organisations to explore all possible options for improving the delivery of their products or services (Drucker, 1994). Construction clients are now expecting a better service and projects that meet their requirements more closely. This has challenged the industry to become more efficient, integrated and more attractive, with benefits both for its potential workforce and society as a whole.

In response, government, industry or research-led construction change initiatives have emerged in most developed countries which set out a vision of where the industry should head to. Some have set specific targets, for example Rethinking Construction (Egan, 1998) and US National Construction Goals (Shaw, 1996). Others have simply defined the way they want to work in broader terms, for example, through integrating the supply chain, industrialisation of the building process and increased technological innovation and use of Information and Communication Technologies (ICT) (Building Policy Task Force, 2000, ISR, 1999, Kohvakka et al., 2001). Sought after improvements, common to most of the initiatives, include reducing construction time and cost, defects, accidents, waste and operation and maintenance costs, whilst improving predictability and productivity.

Figure 1.1 illustrates these global trends which have led to the identified construction drivers and instigated the targets for improvement.

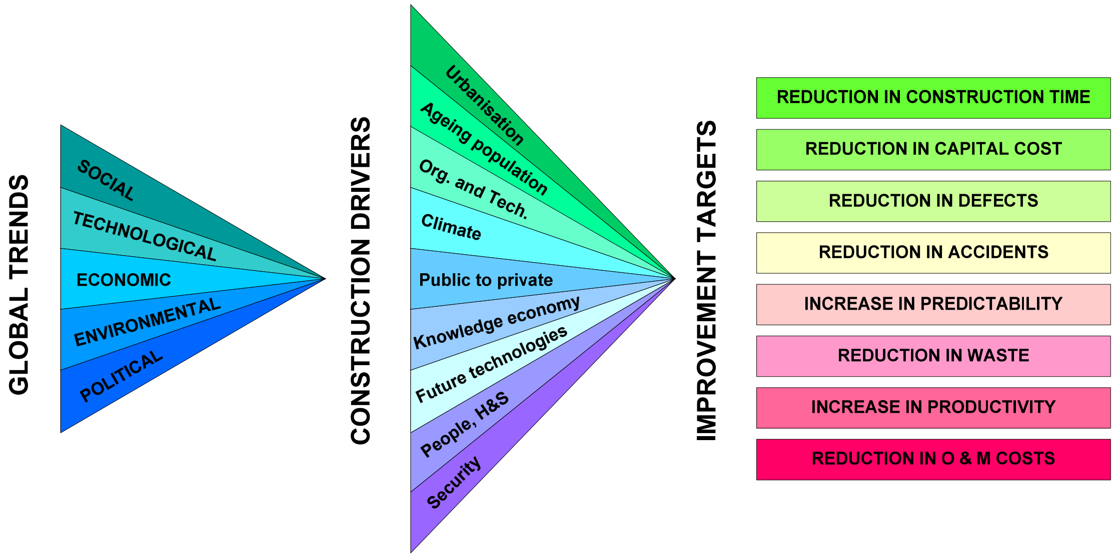

Figure 1.1 Key issues facing 21st century construction

1.2.2 ICT IN CONSTRUCTION

Effective communication is vital in construction due to the large number of project participants, the separation of design and construction disciplines and the geographically dispersed nature of the projects (Barrie & Paulson, 1992). Thus, the improvement of communication in the construction industry has been a target of practitioners and researchers for many years.

As stated above, ICT is often viewed as a mechanism to enable positive change within the construction industry. Information technology has formed a major research topic in the construction industry for the last twenty to thirty years.

The use of information technology within the construction industry has seen the isolated development of functional, departmental or organisational solutions. This has resulted in the so called “islands of automation” illustrated by Hannus (1998b). In recent years the drive towards standards and interoperability, aided by the advent of the Internet, is trying to provide bridges to link these islands together.

Although great strides have been made in the use of IT in construction, technology on its own cannot provide the answer to the need for greater efficiency and quality in construction. Inappropriately applied, new technologies can simply reinforce outdated and wasteful processes. Change should be approached by first addressing the culture, then defining and improving processes and finally applying technology as a tool to support these cultural and process improvements (Egan, 1998).

1.2.3 MOBILE TECHNOLOGIES

Businesses are now beginning to recognise the importance of mobile workers and the impact these employees have on the enterprise. With the introduction of laptops into the work environment as a substitute for personal computers (PCs), the potential of the mobile worker became evident (Faigen & Fridman, 2004). There are two streams of technological development that have been instrumental in the support of the mobile worker: wireless technologies; and portable computing devices.

Wireless developments began back in 1895 when Guglielmo Marconi showed he could send signals by using electromagnetic waves to connect a transmitting and receiving antenna. The first pocket calculator went on sale in 1971 and the capabilities of mobile computing have been developing ever since (e.g. the Osbourne, 1981; Husky, 1981; and the Apple Newton MessagePad, 1993). Three paths of development have been followed: the miniaturisation of desktop computers, the increasing functionality of pocket calculators and the advancement of the mobile phone resulting in manufacturers of mobile devices coming from a diverse range of companies in different industry sectors (e.g. Microsoft, Casio and Nokia). Figure 1.2 provides an overview of the key development dates.

Adoption of these technologies was usually by vertical market rather than satisfying horizontal demands. One of the earliest adopters was Federal Express (FedEx) who provided couriers with the Digitally Assisted Dispatch System (DADS) in 1986. Table 1.1 provides details of some of the early adopters of mobile technology in various industry sectors. The advent of the Internet and email has now instigated the development of horizontal applications such as mobile email and personal information management applications (PIM).

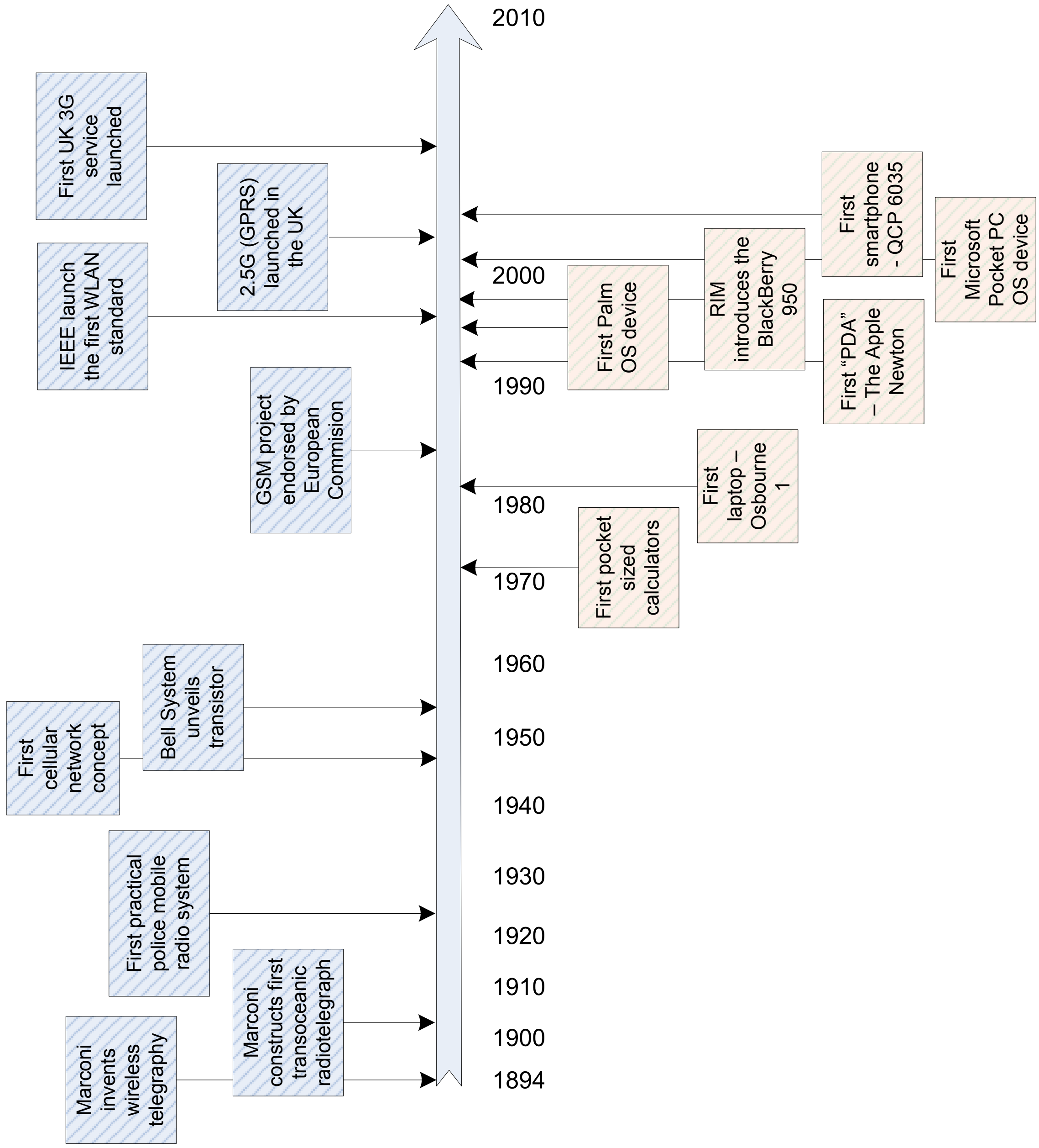

Figure 1.2 Key points in mobile developments (adapted from Faigen & Fridman, 2004)

Table 1.1 Applications of Mobile Computing (drawn from Dhawan, 2005, Escofet, 2004)

Industry	Example applications	Key benefits
Utilities	British Gas (UK) field engineers install and repair central heating systems. In 1996 they were provided with laptops which became wirelessly enabled through GSM in 1997. They are now undergoing their third deployment, switching from laptops to PDAs.	Reduced property footprint (100s of buildings down to 7) Reduced administration staff (nearly 13,000) Increased productivity (ten jobs per day instead of four)
Transportation	Britannia Airways (UK) supplied all of its cabin crew and pilots with wirelessly enabled PDAs and laptops in 2003. In the terminal building the devices automatically download via Wi-Fi all of the necessary flight information.	Savings in support costs (£400,000 over four years) Fuel savings due to more accurate calculations and less weight of paper.
Emergency services	Staffordshire Police (UK) officers were supplied with GPRS-enabled PDAs to wirelessly interact with back-office crime-reporting applications and the Police National Computer records in 2003.	Increased police visibility (more time spent on the street than in the station) Police officers are better prepared to apprehend suspects
Logistics	UPS (Global) first deployed a mobile PDA solution in 1990; this went wireless in 1993. The bespoke device, DIAD (Delivery Information Acquisition Device) provides its drivers with parcel delivery information.	Improved customer service (immediate access to delivery information on more than five million UPS packages daily) Increased productivity Improved competitor advantage
Healthcare	Royal District Nursing Service (Australia) started using the Apple Newton in 1997; providing information to their 1000 district nurses. In 2002 they moved to a GPRS Tablet PC system and can now carry out real-time searches on patient histories, and examine records of past treatment methods whilst they are actually with the patient.	Increased patient time (481,000 hours of care per year expected to increase by up to 2,500 extra hours per week) Data entry and integrity improved
Retail	Marsh Supermarket (USA) was the first supermarket to scan and sell a UPC bar-coded item in 1974; a packet of chewing gum. Since then retailers have taken the lead in the use of Auto-ID technologies with Wal-Mart being the first to insist on RFID tags on its stock.	Reduced labour time at the checkout Capture of customer preferences leading to loyalty cards Automated ordering to replenish stock

1.3 THE RESEARCH CONTEXT

1.3.1 THE AUTHOR

The author has been employed by Arup since 1993 and is currently an Associate specialising in the application of information technology within the construction industry. In 1999, having gained experience in civil engineering design and project management, the author was engaged in the initiation and development of Arup's project collaboration tool, '*Integration*'. This led to recognition that, although collaboration tools facilitate the flow of electronic information between members of a construction project, the flow comes to an abrupt halt when it reaches the construction site. It usually only reaches selected personnel in the site office, and thus many of the efficiency and knowledge-based benefits of collaboration tools are lost. This Engineering Doctorate was initiated to explore the area further.

1.3.2 INDUSTRIAL SPONSOR

Arup provided the industrial sponsorship for the research undertaken and presented in this thesis. Arup is an international engineering consultancy, currently operating out of 73 offices in 32 countries, with 7000 members of staff functioning in a number of inter-related practices. This research was supported by the Enterprise Systems Group who are responsible for establishing and enhancing business support systems within Arup that provide a global platform for the efficient and cost effective management of business processes and project management activities.

Arup has innovation and leading-edge use of technology at its core. In 1964, Arup was the first consulting engineering firm to install an in-house computer, following its ground-breaking use of computers to aid the design of the Sydney Opera House. In line with this drive to understand and utilise appropriate new technologies and recognition of Arup's position within the construction information life-cycle, it was determined that the adoption of mobile technologies to support the delivery and collection of data at the point of activity should be explored.

1.3.3 DEPARTMENT OF TRADE AND INDUSTRY

Department of Trade and Industry (DTI) support has been fundamental to the success of this research. The initial phase of the project was supported by the Fast Track scheme which aimed to promote and assist in the capture of innovative activity within the construction sector and to communicate the results for maximum impact. This supported the author's secondment to Carillion to work on the M6 Toll project as a site engineer to provide a personal insight into the information needs of site personnel.

The second phase of the project was supported under the Partners in Innovation (PII) programme in 2002. PII is a collaborative scheme which provides up to half the costs of research and innovation (R&I) projects within the construction sector. It is open to all UK companies, industry bodies, institutions, research and technology organisations and universities. Under this scheme, Construction Opportunities for Mobile IT (COMIT) was established to bring together representatives from construction, technology, research and dissemination organisations to facilitate the realisation of business benefits from the adoption of mobile information and communication technologies. This project was led by Arup in partnership with Loughborough

University and BSRIA, with the author taking the role of Project Manager. COMIT provided the supporting mechanism for conducting the second phase of the research contained within this thesis. Further details of the COMIT project are given in Section 4.2.3.3 and the COMIT website can be viewed at www.comitproject.org.uk.

The DTI backing substantially enhanced the profile of this research project and provided a mechanism to encourage industry participation, ensuring that the work undertaken was directly relevant to current industry needs.

1.4 AIM AND OBJECTIVES

1.4.1 THE OVERARCHING AIM

This project aims to facilitate the realisation of business benefits from the adoption of mobile information and communication technologies, both in a company and project environment. The project focuses on the application of mobile computing technologies to enhance key processes and the delivery and collection of information from mobile workers.

1.4.2 OBJECTIVES

The specific objectives of the project are:

1. to understand the information requirements of relevant personnel, particularly at points of activity remote from normal office systems;
2. to recognise the key communications between mobile workers, their company and the project team and look for ways to support these using existing and emerging mobile IT;
3. to establish the business case for the use of mobile technologies to facilitate relevant communications in construction;
4. to analyse attitudes towards the use of IT in construction and discover any cultural or other barriers to its implementation.

1.5 JUSTIFICATION AND SCOPE

1.5.1 PROBLEM DEFINITION

The Construction Industry requires its personnel to be mobile in order to complete the realisation of a project. To carry out their job function, communication with others is essential and quality, quantity and timing of information can either hinder or facilitate successful results. It has been suggested that the cost of construction can be reduced by 25% through the efficient transfer of information (Davidson & Moshini, 1990).

The Construction Industry's drive towards utilising IT to enhance communication both within a company and between clients, consultants, suppliers, subcontractors and contractors has, to date, ignored the need to deliver information effectively to personnel at the point of activity (e.g. whilst on site or attending a client meeting). Mobile workers (including many point-of-activity workers) are therefore prevented from efficiently and effectively contributing to the information flows that are crucial to any business. In addition, error rates in data collection are too high; the speed and immediacy of data receipt, capture and feedback requires significant improvement;

information exchange is expensive; and audit trails are not automatically produced. Delays, variable productivity, accidents and quality problems are thus commonplace in the industry (Egan, 1998, Latham, 1994).

Researching the use of mobile computing in construction began in earnest in the mid-nineties (Alexander 1996, Cox and Issa 1996, Liu 1995, McCullouch and Gunn 1993). Potential applications include: site diaries (Scott and Assadi 1997), maintenance conditions (Rojas and Songer 1997), progress records (Cox et al. 2002), and monitoring piling activities (Ward et al. 2003).

Construction professionals are becoming aware of the benefits that mobile computing technologies could bring to their work activities. However, they appear unsure how to implement them on their projects and unwilling to take the risks associated with being an early adopter, such as implementing unfamiliar technologies and uncertainty of the return on investment.

Technology providers are very aware that the construction industry provides obvious applications for their tools. They are certainly committed to entering the market, with many firms now including construction as a target vertical market in their business strategy. However, they are experiencing difficulties in persuading construction professionals to try something new. This may arise from their inexperience in supplying the construction industry and therefore their lack of understanding of the market.

This project seeks to provide a body of knowledge to enable them to better understand each other's needs and values and hence provide the most effective solutions both technically and commercially.

1.5.2 SCOPE OF THE RESEARCH

This research project is primarily concerned with mobile construction workers, understanding their needs and providing solutions to support them. The terms mobile and wireless are often considered interchangeable; however, the following examples extended from the ITU-R Vocabulary of terms for wireless access (ITU, 2005) illustrate the difference between them (Figure 1.3):

A *'fixed worker'* will normally work using a PC or laptop whilst sitting at a desk at his main place of work. Communications infrastructure can be provided by either a fixed local area network (LAN) or a wireless LAN (WLAN) where cabling is not appropriate; this is termed *'fixed wireless'*. An example worker would be a design engineer based in an office.

A *'nomadic worker'* will normally work using a laptop or a PC whilst stationary. However, they will move from place to place in between working periods. Communications infrastructure can be provided by either a fixed LAN (the user simply plugs in their laptop on arrival at a LAN - becoming a fixed worker) or a WLAN or mobile network providing coverage in the area of work (becoming a fixed wireless worker). An example would be a contracts manager that visits the temporary offices (portacabins) on several company sites.

A *'mobile worker'* will normally use a mobile device (e.g. handheld computer or digital pen) whilst moving around or remaining stationary for short periods of time. Communications infrastructure can be provided by either a WLAN providing coverage in the area of work or a mobile (radio or telephone) network. If the worker simply collects the data whilst mobile and then goes back to his desk to synchronise the information, he then becomes a fixed worker. An example would be a maintenance engineer that visits many client sites or a health and safety officer conducting an inspection out on site.

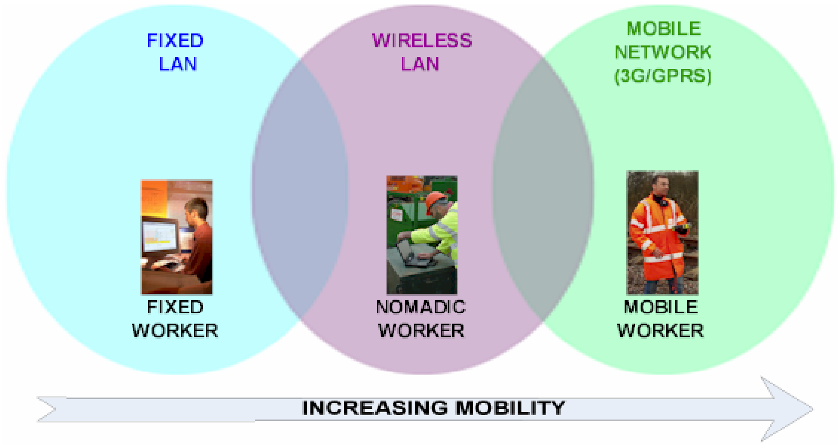

Figure 1.3 Levels of mobility

1.6 THESIS STRUCTURE

This thesis documents the research undertaken in partial fulfilment of the requirements for the award of an Engineering Doctorate (EngD) of Loughborough University. It is structured as follows:

Chapter 1 introduces the research project, provides an introduction to the general subject domain, identifies the aim and objectives and justifies the need for the research, and sets it within an industrial context.

Chapter 2 provides an overview of previous work in this domain and highlights how this research project builds on those which have preceded it, demonstrating innovation in the application of knowledge to the engineering business environment.

Chapter 3 reviews a range of research methodologies and details those adopted for use in this research project.

Chapter 4 details the work undertaken to meet the research project's aim and objectives.

Chapter 5 concludes by summarising the key findings of the research, sets out how the project has contributed to knowledge and practice, identifies the impact of the research on the sponsor and wider industry, and presents areas suitable for further research.

Appendices 1 to 4 contain the four peer-reviewed published papers that support this research. These papers are an integral part of, and should be read in conjunction with, this thesis.

1.7 SYNOPSIS OF PAPERS

All of the papers completed as part of this research, and included in this thesis, are listed in Table 1.2. Alongside the title, status and place of publication for each paper, a brief description is provided highlighting its contribution to the fulfilment of the research aim and objectives. Each paper has been identified by a number together with the corresponding appendix number.

Table 1.2 List of papers

ID	Title	Journal/ Conference	Status	Description
Paper 1, Appendix 1	Mobile communications for on-site collaboration	Proceedings of ICE, Civil Engineering (2002)	Published	This paper introduces the problem of information delivery to the point-of-activity on a construction site. It highlights site information needs, details available mobile technologies and identifies barriers and benefits to their use.
Paper 2, Appendix 2	Making the case for mobile IT	International Conference on Computing in Civil Engineering (ICCC 2005)	Published	This paper details eleven case studies undertaken to demonstrate the use of mobile technologies by point-of-activity workers in construction, their influence on process efficiency, improved opportunities for data collection, and that rapid return on investment is usually achievable.
Paper 3, Appendix 3	Mapping site processes for the introduction of mobile IT	European Conference on Products and Processes Modelling (ECPPM 2004).	Published	This paper documents activities undertaken to better understand which construction processes would derive most benefit from the application of mobile information and communication technologies.
Paper 4, Appendix 4	Mobile IT support for construction process improvement	Automation in Construction	In Press	This paper brings together the visions for ICT in construction and the change requirements of the construction industry. It illustrates how each of the areas highlighted for improvement can be addressed through the use of mobile IT, both in the present and the future.

2 RELATED WORK

2.1 INTRODUCTION

This chapter sets the research undertaken in the context of work already carried out in this subject domain. It details the results of the literature review carried out in order to provide a sound knowledge framework through which the context of the subsequent research project can be established. It then illustrates how the aim and objectives for this research were derived, ensuring that the research built on previous work and avoided reinventing the wheel.

2.2 PRIMARY RESEARCH AREAS

In accordance with the problem definition set out in Section 1.5.1, the primary areas of research to explore were communication and information needs, and applications of mobile technologies, in construction. However, these should be viewed in the broader contexts of communication, the construction industry and information technologies in order to learn from theory and practice from outside the construction industry as well as understand the drivers for change and the context of this research within construction (Figure 2.1). The primary research areas are discussed in detail in this chapter and the broader research relevant to this study is referenced throughout this thesis.

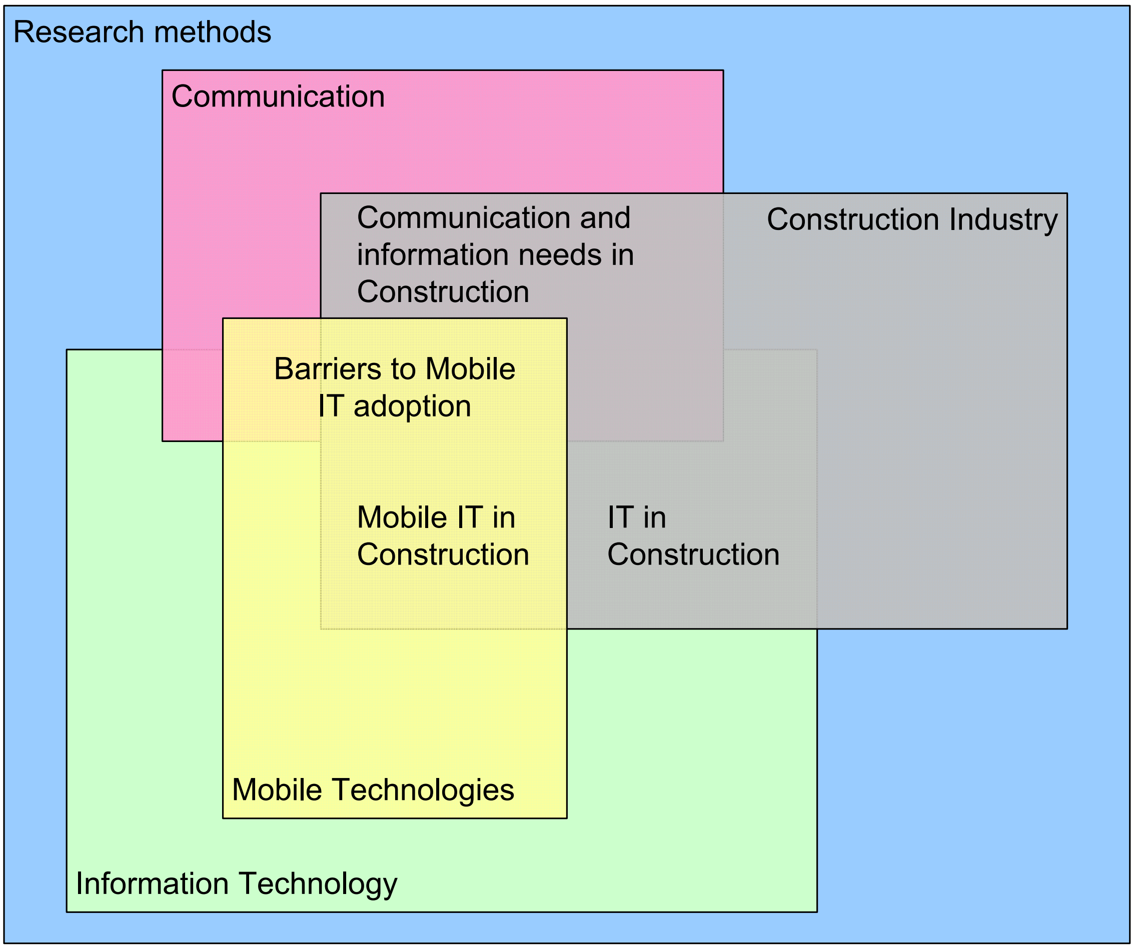

Figure 2.1 Research areas

2.2.1 COMMUNICATION AND INFORMATION NEEDS IN CONSTRUCTION

Hundreds of definitions of the term "communication" have been offered over the years; these definitions are never true or false, they are only more or less useful. Eisenberg and Goodall (1993) identify four major definitions of communication:

- communication as information transfer;
- communication as a transactional process;
- communication as strategic control; and
- communication as balancing creativity and constraint.

2.2.1.1 Communication needs in construction

The importance of communication in construction is well illustrated by the following quotation:

"We don't sell construction work anymore. We sell people and communication"

- Roger Baldwin – VP Maescher Construction

To function effectively, a construction company must have communication systems of different types: inter-personal, inter-departmental, and inter-organisational (Guevara & Boyer, 1981). Inter-organisational communication is of particular relevance to a construction project. Eisenberg et al. (1985) define inter-organisational communication as a communication network that ties together independent organisations in an attempt to reduce environmental uncertainty.

Effective communication is vital in construction due to the large number of project participants, the separation of design and construction disciplines and the geographically dispersed nature of the projects (Barrie & Paulson, 1992). Thus the improvement of communication in the construction industry has been a target of practitioners and researchers for many years. The requirement for this improvement is now being driven by both technical innovation and business motivation (Thorpe *et al.*, 1995).

There are numerous studies that have highlighted the problems inherent in construction communications (Al-Hammad, 2000, Egan, 1998, Guevara & Boyer, 1981, Latham, 1994, Murray & Thorpe, 1996). Murray and Thorpe (1996) carried out a Site Communications Survey as part of the COMPOSITE (COmmunications by computer between Main Participating Organisations on SITE) project. The major communication barriers were identified as volume and feedback of information. Guevara and Boyer (1981) also found that lack of feedback contributes to all three major communication problems:

- Over-load: A situation in which an individual has more information than can be utilized.
- Distortion: Message distortion occurs when the nature of the message is changed by adding or deleting bits of information. It differs from information processing in that the addition or deletion of information is done to protect an individual and to ensure his or her status.
- Gate-keeping: The act of intentionally withholding information.

All construction projects generate paper data, and the larger the project, the larger the volume of records to be managed (Flowers, 1996). A conclusion that is often drawn is that effective communications on site are held back by the predominantly paper-based world (Moniem, 2000). Electronic exchange and production of information should alleviate these problems. However, unless the exchange of electronic information is properly implemented and managed this will not always be the case.

2.2.1.2 Information needs in construction

In its broadest sense, information can be defined as the data and messages that are transmitted between people within a communications network (Mead, 2001). The literature review revealed that there have been many attempts to categorise/identify construction information. Table 2.1 illustrates that researchers have filtered site information to a greater or lesser extent. A combination of these categories will be utilised in this research.

Table 2.1 Construction information categorisation

BT (1995)	Murray and Thorpe (1996)	De La Garza (1998)	Scott (1995)
Technical	Confirmation of Verbal Instructions	Requests for Information	Contract Documents
Commercial	Technical Queries	Materials Management	Working Drawings
Management	Site Instructions	Equipment Management	Progress records and plans
Control	Subcontractor Site Instructions	Cost Management	Financial and Measurement Records
	Dayworks	Schedule and Methods	Quality Records
	Requisitions	Site Record Keeping	Safety and Accident Records
	Site Programmes	Submittals	Amendments to the contract
	Method Statements	Safety Records	Plant and materials Records
	Sketches	QA/QC	Contractual Claims
	Drawings	Future Trends	Miscellaneous
	Drawing Administration		
	Application for Payment		
	General Correspondence		
	Photographs		
	Video		

Tenah (1986) researched this area from a slightly different angle, looking at the information needs of specific construction personnel. His study found a wide array of functions within construction organisations and that information needs are inextricably linked to the management responsibilities of each member of the project team. Table 2.2 shows an example of the foreman's information needs. He concluded that personnel who have good access to timely accurate information will:

- reduce or maintain project durations;
- make better use of resources;
- increase labour and equipment productivity; and
- decrease cost.

Table 2.2 The Foreman's functions and information needs (Tenah, 1986)

Primary functions	Primary information needs
Organises and coordinates employees engaged in a specific craft or function on a construction project. Reads and interprets drawings, blueprints, and specifications. Allocates, assigns, and inspects work. Administers union agreements and safety enforcement, hires and trains employees.	Blue prints, specifications, and other contract documents. Local union activities, safety regulations and laws, labour agreements, quality control, and testing regulations. Shop drawing and sample control, procurement status, bar chart by system or area, production schedules, and field performance reports.

Three areas have been cited for improvement: data collation, information transfer and information retrieval. As illustrated below, these functions are hindered because most project information is currently stored on paper, which is difficult to access and time-consuming to search.

The ability to quickly convert data into information, while at the same time reducing the drudgery associated with many of the administrative tasks, improves both staff efficiency and work interest (Flowers, 1996).

Figure 2.2 (Newton, 1998) shows that 65% of contractor-rework is attributed to insufficient, inappropriate or conflicting information. Site issues need to be resolved quickly and efficiently to avoid downtime, rework and waste with the associated cost overruns and this often requires collaboration between on and off-site personnel (Miah *et al.*, 1998). By enhancing information flow between the different site processes and teams, it is easier to monitor, control and assess the project progress and hence integrate the on-site process (Moniem, 2000). It has been proposed that the cost of construction could be reduced by 25% through the efficient transfer of information (Baldwin *et al.*, 1996, Davidson & Moshini, 1990).

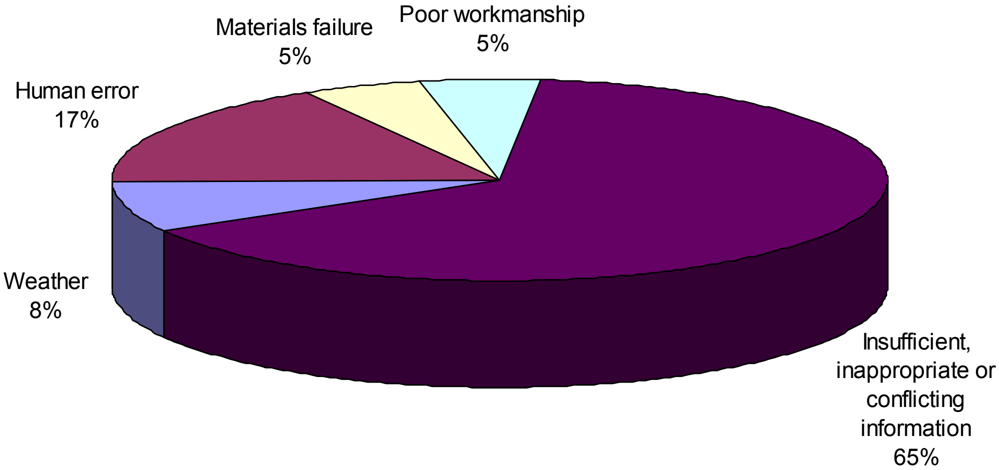

Figure 2.2 Contributory factors to contractor rework (Newton, 1998)

Specifically, if information retrieval can be enhanced there are significant savings to be made. A recent study (Gallaher et al., 2004), estimated the cost of inadequate interoperability in the U.S. capital facilities industry conservatively to be $15.8 billion per year, the majority of this, $9.1 billion, is in operation and maintenance costs. An inordinate amount of time is spent locating and verifying specific facility and project information from previous activities. For example, as-built drawings (from both construction and maintenance operations) are not routinely provided and the corresponding record drawings are not updated. The cost of time spent ensuring that the information accurately represents what is set in place is estimated to be $4.8 billion.

2.2.2 MOBILE IT IN CONSTRUCTION

Information technology has formed a major research topic in the construction industry for the last twenty to thirty years. It has been recognised that the use of IT could eliminate many of the problems, outlined above, associated with paper-based documentation: duplication, feedback, quality, exchange, awareness, illegibility, format, volume, cost, queries and out of date information (Murray & Thorpe, 1996).

However, research in Australia shows that the construction site is information poor in terms of the tools that site personnel have at their disposal and the percentage usage of IT is lower on site than in the office. The existence of this gulf means that the kind of efficiencies that are necessary to improve the construction industry will be very difficult to be achieve (Newton, 1998). Mobile IT has been proposed as a means to bring the capabilities, and hence the benefits, of IT to the construction site (Paper 1, Appendix 1).

Researching the use of mobile computing in construction began in earnest in the mid-nineties. Research carried out up to the year 2000 primarily focussed on developing prototype solutions for one or two processes to illustrate the potential benefits. Approximately half of these were piloted with a construction or facilities management company. The processes that were predominantly addressed at first were maintenance inspections (e.g. Nathwani *et al.*, 1995), followed by materials management (e.g. Baldwin *et al.*, 1994) and progress monitoring (e.g. Repass *et al.*, 1999). In contrast, the

MICC (Mobile Integrated Communications in Construction) project, and de la Garza (1998) provide a broader picture, as outlined below.

MICC was a European funded project which aimed to introduce the use of on-site mobile communications as a way of improving the global competitiveness of the European construction sector (Deguine *et al.*, 1999). Whilst the MICC project commenced in 1995, and information technology capabilities have progressed substantially since then, it was important because it recognised the need for electronic data delivery to and from construction sites and illustrated how sites can be connected back to the head office via a dedicated ISDN link. It also began to address the needs of point-of-activity workers, although only voice services were provided due to the lack of functionality available at that time to deliver data wirelessly.

MICC's user driven approach, harnessing "existing or soon to be" mobile technology to meet user requirements, its focus on industry involvement and real-life trials, and its intention through an industry forum (comprising 26 companies) to bridge the gap between construction companies and technology providers was also adopted in this research project.

De la Garza (1998) examined the trade-off between the value of information being delivered remotely and the cost of delivering it. Two example scenarios were provided that illustrate the value of, and cost of, transmitting the information versus the time of day that the information is sent. It poses two questions for a contractor planning to implement a wireless solution to consider when deciding on an appropriate process:

1. Remote data collection – Is the additional cost of transmitting the information wirelessly outweighed by the added value of receiving the information earlier?
2. Remote data retrieval – Is the additional cost of retrieving the information wirelessly less than the additional costs incurred by leaving the site to retrieve the information (e.g. reduced productivity of the gang)?

This work indicated that further research needs to be carried out in this area, in order to provide a comprehensive business case for the use of mobile I.T. applications/solutions.

From 2000 onwards, there has been an increase in the number of papers published that address this area. However, the focus has still been on the prototype development of PDA solutions (Menzel *et al.*, 2004, e.g. Pilgrim *et al.*, 2002). Interestingly, during this period there has been a decline in direct industry involvement. Reasons given for this include the difficulty of obtaining accurate data from field experiments on commercial construction jobsites, where personnel are mobile, in a dangerous setting, and under intense pressure to complete the task at hand. This has necessitated the use of engineering students to act as end-users during some trials (e.g. Elvin, 2003). The papers published during this period (i.e. during the course of this EngD study) that are most relevant to this research are outlined below:

Saidi *et al* (2002) examined the value of the use of handheld computers in construction. Six processes were selected and broken down into a detailed set of elementary tasks with estimated minimum and maximum durations. For all apart from one process (which used field observations and interviews), the method was applied to theoretical models of the construction activities involved rather than to actual activities on a construction project. The authors justified this use of estimated times by stating that the differences in task times between the traditional process and the 'mobilised' process are the focus. This research showed that in each case the use of handheld computers would eliminate some elementary tasks altogether and provide substantial time reductions. The authors recommended that the lack of empirical data on PDA performance in construction could be improved through well-documented pilot projects at construction companies and through controlled experimentation with PDAs under simulated environments. They also provided an indication of construction tasks that were suited to the use of PDAs and those that were not (Table 2.3).

Table 2.3 Tasks for which PDAs are and are not suited (Saidi *et al.*, 2002)

Tasks that are suited	**Example**
Tasks that require access to large amounts of text information	Reading Material Safety Data Sheets (MSDS) sheets, building codes, knowledge base etc.
Tasks that require viewing a small detail of a document	Viewing a close-up of a steel beam connection diagram
Tasks that require the entry of binary data	Answering yes/no questions, checking-off items on punch lists
Tasks that require the entry of data into a form	Filling in a safety or equipment usage report, recording material receiving information
Tasks that require instant transfer of small amounts of information to and from a network	Sending and receiving emails, looking up the latest material procurement information
Tasks that are NOT suited	**Example**
Tasks that require computer processing power comparable to that found in desktop computers	Editing a 3-D construction drawing
Tasks that require a “big-picture” view of a document	Viewing a drawing or network schedule
Tasks that require a constant (i.e. always on) connection to a computer network	Working with data stored on a mainframe
Tasks that require a considerable amount of manual data entry (or writing)	Writing a progress report
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
Tasks that actually put work in place	Nailing, cutting, digging etc.

Communication problems in the industry are most apparent in the breakdown of information exchange at the point of work on the construction jobsite. Elvin (2003) postulated that the use of tablet and wearable computers improves communication between the fieldworkers at the point of work on site and off-site collaborators in building design and construction. A series of experimental trials showed that although productivity declined when using the devices instead of paper (in this case by 8%), the amount of rework required was significantly reduced (by 66%). The study concluded that communication was improved; however, further study was recommended on measuring the productivity impacts of electronic versus paper document management at the point of work on larger projects.

Olofsson and Emborg (2004) conducted a series of in-depth interviews to understand:

1. where can mobile applications be deployed in the construction sector;
2. what is the economic impact of mobile applications in construction; and
3. how should mobile applications be introduced in specific operations.

The problems, mobile solutions, costs and benefits were analysed for three scenarios; installations and building services, a road construction project and ready mixed concrete delivery. In each of these scenarios it is shown that return on investment is possible. Figure 2.3 (the size of the circles is proportional to the estimated total monetary value of the benefits derived and the additional costs incurred) and illustrate the road construction project scenario.

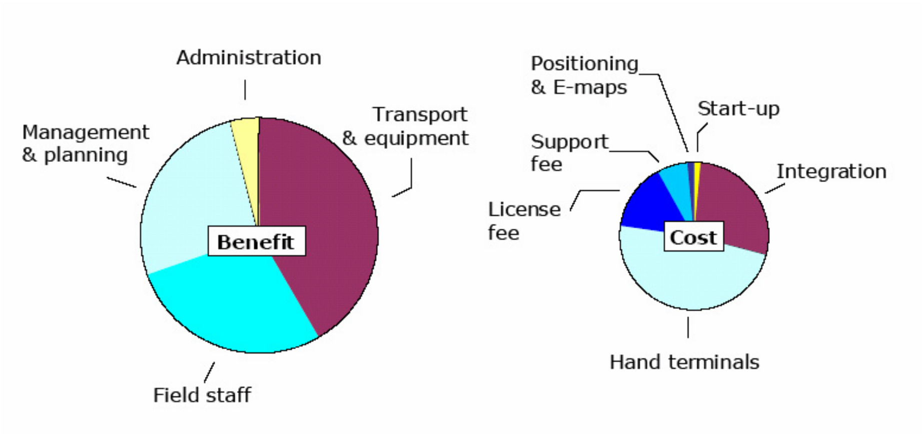

Figure 2.3 Estimated ROI for the road construction project (Olofsson & Emborg, 2004)

Table 2.4 Identified problems and solutions for road construction (Olofsson & Emborg, 2004)

Category	Identified problem	Mobile solution
Management and planning	The main contractor often has frequent and extensive meetings with subcontractors and the client to resolve coordination issues	Generated follow-up reports can automatically be sent to all actors. Better tools for the daily planning and operations reduce the need for meetings.
Transport and equipment	Since the equipments are often spread over a large area it is difficult to make use of available resources.	Positioning and state of equipment and field staff. Use of resources can be based on availability and location.
	Problem receiving and taking deliveries to the right location since no specific delivery addresses exist on the site.	Positioning and external notification of incoming deliveries including the name of the orderer and date of order.
Administration	Paper based work reports, delivery consignment notes get lost or the signature of the receiver is illegible. This creates problems for the accounting department.	Electronic consignment notes, work reports, signatures and bills would significantly facilitate the administration, such as attest of bills and invoices.
Field staff	Coordination of daily operation. Location of staff in space and time.	Login and positioning makes the filed staff located and online during working hours.

2.3 CONTRIBUTION TO RESEARCH

Previous research has largely focussed on one-off, single process, mobile IT prototype developments and, in limited cases, pilots. Little consideration has been given to what is required to instigate mainstream adoption of these applications in the construction industry.

Research into the adoption of IT by the construction industry has highlighted the need to clearly demonstrate business benefit and return on investment as a determinant of successful approval to proceed and subsequent implementation (Andresen *et al.*, 2000, CIRIA, 1996), however, to date, little research has been conducted in this area for mobile IT.

Another commonly cited barrier to IT adoption is a lack of awareness about information and communication technologies (Love & Irani, 2001) and the lack of exemplars demonstrating its successful use by others (Anumba, 1998). Research conducted to date shows that there is a significant lack of case study material where the researcher has not been part of instigating the solution and developing the prototype. This is to be expected as the use of mobile IT in construction is relatively new and hence there are limited applications which would provide case study material. However, there are now examples of industry use of mobile IT appearing in the construction press (Delargy, 2000, Hansford, 2001).

There is also only limited material that provides guidance to industry as to which processes are most suitable, and addresses the human factors that will govern user acceptance. This research will address the shortcomings outlined above by focussing on a broad range of applications, drawn from industry needs via a collaborative forum approach, to develop a knowledge base that will inform investment and implementation plans and thus facilitate mainstream adoption of mobile IT applications in the construction industry. It should be noted that during the course of this research, parallel research projects have been conducted examining similar areas; however, these projects have not directly engaged with industry to such an extent.

2.4 SUMMARY

This chapter has provided an overview of the relevant research that has been conducted within the primary areas of research: communication and information needs, and applications of mobile technologies, in construction. This serves to provide a knowledge foundation from which to learn, and to build upon, ensuring the research conducted for this thesis adds to rather than duplicates existing or other ongoing work.

3 RESEARCH METHODOLOGY

3.1 INTRODUCTION

Research methodology refers to the principles and procedures of logical thought processes applied to scientific investigation (Fellows & Liu, 1999). This chapter discusses briefly the methodological approaches that are available and sets out the reasoning behind the methodology selected for this research project. It then details the research methods that were used and finally provides the overall research design.

3.2 METHODOLOGICAL CONSIDERATIONS

The conduct of research is guided by a research perspective or paradigm comprising ontological (what is assumed to exist), epistemological (the nature of valid knowledge) and methodological (the rules of inquiry) assumptions that together frame the nature of the research and the role of the researcher in the scientific inquiry. However, these perspectives or assumptions may often be held implicitly, in that the governing structures under which the research is produced are not explicitly discussed or reflected upon by the researcher (Orlikowski & Baroudi, 1991).

This research was instigated by the author's belief that by providing construction workers with a means to capture and retrieve data electronically at the point-of-activity, communication and management processes could be improved. The author is not primarily concerned with the intricacies of the technologies themselves but more with the process improvements which they could make possible, and identifying and understanding the cultural and business barriers to their adoption which currently exist.

Although an ontological and epistemological approach was not defined at the outset of the research, an approach has been naturally assumed by the author. It is important to enhance the reader's understanding of this thesis, that the author's inherent beliefs regarding the nature of the phenomenon under investigation and hence the research paradigm adopted should be made apparent. Therefore, the framework within which this research project has been conducted is examined here.

In general, the philosophical perspectives for research have been represented as two polemic, divided and polarised camps (Fitzgerald & Howcroft, 1998). Research paradigms are typically illustrated in terms of the dichotomies at each level of assumption, as illustrated in Figure 3.1. It should be noted that the dichotomies of the research framework are merely the extremes of a set of continuums, and in reality positions exist somewhere between these limits. The following sections look at each level in turn.

3.2.1 ONTOLOGY

Ontology refers to the nature of the world around us; in particular, that slice of reality which the researcher chooses to address (Hirschheim, 1992). At one extreme one can be a relativist and hold a belief that multiple realities exist as subjective constructions of the mind. At the other extreme is a realist who holds the belief that the external world consists of pre-existing hard, tangible structures which exist independently of an individual's cognition (Fitzgerald & Howcroft, 1998).

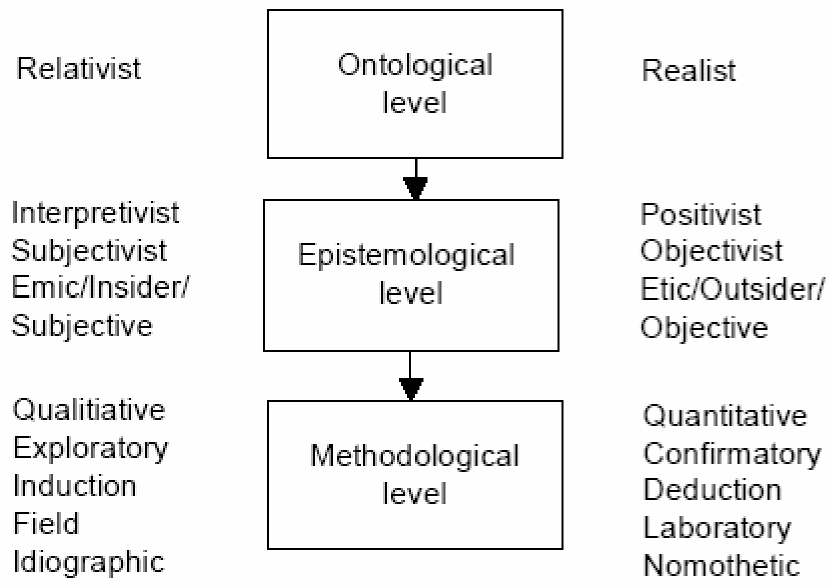

Figure 3.1 Hierarchy of paradigm characteristics and major related dichotomies in Information Systems research (Khazanchi & Munkvold, 2003)

This thesis, in common with many other studies, holds to the realist perspective. However, it takes the form of critical realism which recognises that there is a reality which exists independently of 'our' experience but acknowledges that discourse shapes reality, and is in turn shaped by it. In other words, all knowledge is local, provisional and context-dependent.

3.2.2 EPISTEMOLOGY

Epistemology refers to our theory of knowledge; in particular how we acquire knowledge. Epistemological approaches have developed through time. Researchers in the natural sciences have traditionally adopted a positivist approach; a belief that the world conforms to fixed laws of causation. This approach has enjoyed great success in the physical sciences where a tremendous growth in knowledge has been experienced, however, its adoption within the social sciences has been less successful and its appropriateness has often been questioned (Hirschheim, 1992).

Early on, many Information Systems (IS) researchers primarily concentrated on technology, and the majority of published IS research reflected a positivistic orientation (Orlikowski & Baroudi, 1991). As the information systems field, within which mobile technologies sits, has developed from computing to information technology (IT) to information and communication technologies (ICT) the number of disciplines which influence this field has grown. IS research now incorporates a number of disciplines, including computer science, management and organisational studies, social science, and philosophy (Klecun, 2004). These influences have generated a move from the positivist position to an interpretivist position; which emphasizes that reality is socially constructed and open to various interpretations both by actors and researchers. A researcher adopting such a perspective seeks to develop a thorough understanding of a phenomenon within a particular cultural and contextual setting (Dube & Pare, 2001). Interpretative research within the information systems field is now becoming more and more popular (Avgerou, 2000).

This study adopts an interpretivist approach, acknowledging that although there have already been successful adoptions of mobile IT solutions within other industries and the construction industry appears to demonstrate a need for mobile solutions as an information intensive industry dominated by mobile workers, there appears to be contextual and cultural barriers to its adoption.

3.2.3 METHODOLOGY

As stated above, there has been a general shift in IS research away from technological issues to managerial and organisational issues. This has created room and opportunity for a multiplicity of research approaches (Keane & Parent, 1998).

There are three main arguments in favour of multi-methodology or a mixed method approach:

1. real world problem situations are multi-dimensional;
2. different approaches are suitable at different stages of the intervention; and
3. using multiple methods can provide triangulation, thus validating the results.

Expanding on the first argument; real world problem situations are inevitably multi-dimensional. Schon (1987) uses the analogy of the swamp to illustrate problems within the real world:

> *"In the swampy lowland, messy, confusing problems defy technical solution. The irony of this situation is that the problems of the high ground tend to be relatively unimportant to individuals or society at large, however great their technical interest may be, while in the swamp lie the problems of greatest human concern. The practitioner must choose. Shall he remain on the high ground where he can solve relatively unimportant problems according to prevailing standards of rigour, or shall he descend to the swamp of important problems and non-rigorous inquiry?"*

In the swamp conditions, there will be multiple actors, multiple perspectives and conflicting objectives. In the case of the situation examined within this thesis, the problem of the successful adoption of mobile technologies within the construction industry can be characterised as a "swampy" problem. As illustrated in Figure 3.2, there are multiple actors (the end-users, the team leaders, the project leadership and the technology providers) potentially within multiple organisations. There are also multiple aspects to be addressed: hardware, software, back-end systems, costs, usability, processes and benefits.

Different approaches tend to focus on different aspects of the situation and so multi-methodology is necessary to deal effectively with the full richness of this real world problem.

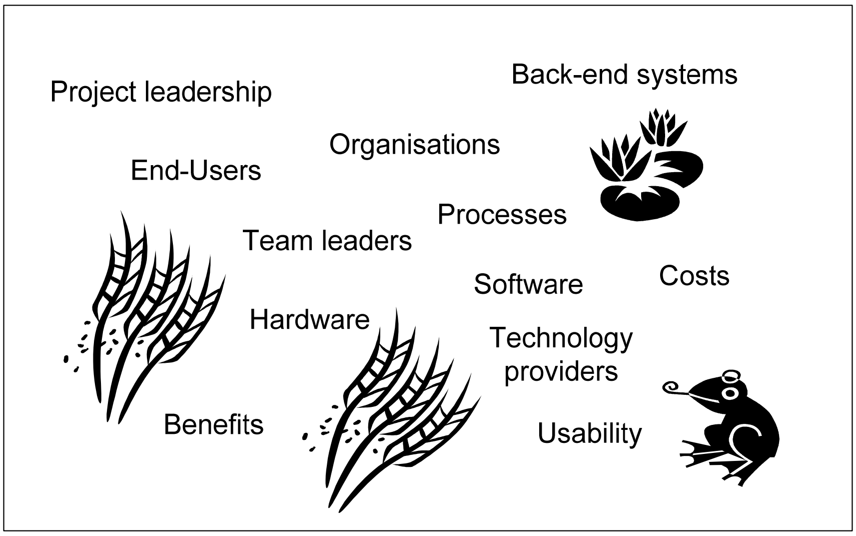

Figure 3.2 The problem "swamp"

Mingers (2002) states that adopting a single approach is like viewing the world through a particular instrument such as a telescope, an X-ray machine, or an electron microscope. Each one reveals certain aspects of the world but is completely blind to others. This ties in with the old proverb cited by Hirschheim (1992) "For he who has but one tool, the hammer, the whole world looks like a nail."

Although concerns have been raised about the philosophical and conceptual problems of combining methodologies from different paradigms, Cavaye (1996) argues that the methods chosen should depend on what one is trying to do rather than commitment to a particular paradigm. In line with this viewpoint, the research undertaken has adopted the approach supported by Falconer and Mackay (1999) that researchers should focus on the nature of the phenomenon to be investigated, rather than the epistemology or ontology, and select the method that can illuminate the phenomenon. Although the research design was formulated prior to the data collection, the research paradigm, described above, within which the research was undertaken has been addressed retrospectively. The next section details the selection of the research methods used and the overall design.

3.3 RESEARCH DESIGN AND METHODS USED

The research undertaken to achieve the stated aim (Section 1.4.1) was conducted in two phases. Phase 1 set out to confirm that there was a need for mobile IT solutions within the construction industry and that these solutions would be accepted and suitable for use by the point-of-activity workers (e.g. foremen and site engineers). Phase 2 aimed to identify suitable processes for the use of mobile IT solutions and what variables would/may influence their successful adoption.

In the course of producing the research design, suitable research methods were explored. Research methods are the techniques used to conduct a research project. Fellows and Liu (1999) state that methods can be broadly categorised as quantitative and qualitative:

- Quantitative Methods — Applied scientific method in which the initial study of theory and literature yields precise aims and objectives with hypotheses to be tested.
- Qualitative Methods — An investigation of the subject is undertaken without prior formulations. The aim is to gain understanding so that theories will emerge.

Quantitative Methods include structured surveys (interviews and questionnaires), experiments, and desk based research of secondary data. Qualitative Methods include unstructured surveys (interviews and questionnaires), case studies, and action research.

In determining which method or strategy to use, it is instructive to ask what form the research questions take. Table 3.1 provides a useful categorisation for selecting the most appropriate method/strategy.

Table 3.1 Relevant situations for different research strategies (Yin, 1994)

Strategy	Form of research question	Requires control over behavioural events?	Focuses on contemporary events?
Experiment	How? Why?	Yes	Yes
Survey	Who? What? Where? How many? How much?	No	Yes
Literature review	Who? What? Where? How many? How much?	No	Yes/No
History	How? Why?	No	No
Case study	How? Why?	No	Yes

The aim and objectives of this research project pose several questions including:

- What are the information and communication requirements of point-of-activity workers when remote from office-based ICT?
- What are point-of-activity workers' attitudes towards the use of IT in construction?
- What are the key processes which will benefit from the implementation of mobile IT?
- What technologies are currently available to support these processes?
- How can mobile technologies deliver business benefits to construction companies?
- Why do mobile technology implementations succeed or fail?

A pluralistic research design advocates the use of multiple approaches within a single study, thus benefiting from the complementary strengths of different methods. Established research methods in both quantitative and qualitative approaches are seen as having a contribution to make at various points in the process, depending upon the existing body of knowledge in the specific area under study, the objectives and perspectives of the research and the quality of available data (Wing *et al.*, 1998).

The questions above, together with the adoption of a mixed method approach, led to the selection of a range of research methods to be used during the course of the research project, these are detailed in the following sections. Figure 3.3 illustrates the overall research process (with reference to the relevant sections in the thesis) and Table 3.2 illustrates which research questions each of the methods have been used to address. For each question a primary method was selected with other methods used to provide supporting information enabling triangulation of the results. This serves to reduce or eliminate the disadvantages of each individual approach whilst gaining the advantages of each, and of the combination – a multi-dimensional view of the subject, gained through synergy (Fellows & Liu, 1999).

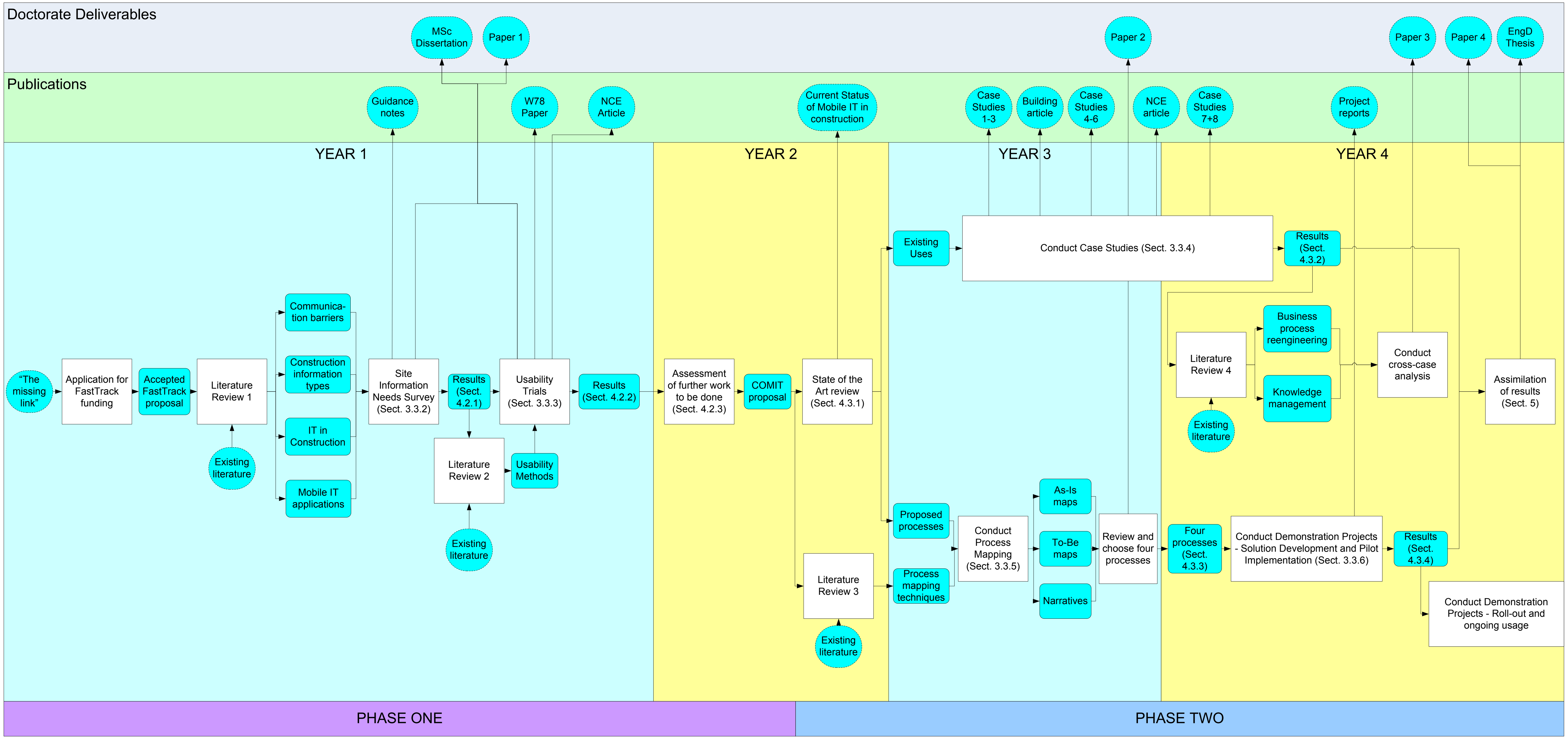

Figure 3.3 Research process

Table 3.2 Research methods used

Key

- **P** Primary method
- **S** Supporting method

Objective	Research questions	Literature review	Survey	Usability testing	Process mapping	Case studies	Pilot testing
1. To understand the information requirements of relevant personnel, particularly at points of activity remote from normal office systems.	What are the information and communication requirements of point-of-activity workers when remote from office-based ICT?	S	P				
2. To recognise the key communications between mobile workers, their company and the project team and look for ways to support these using existing and emerging mobile IT.	What are the key processes which will benefit from the implementation of mobile IT?	S	S		P	S	S
	What technologies are currently available to support these processes?	P		S		S	S
3. To establish the business case for the use of mobile technologies to facilitate relevant communications in construction.	How can mobile technologies deliver business benefits to construction companies?	S			S	S	P
4. To analyse attitudes towards the use of IT in construction and discover any cultural or other barriers to its implementation.	What are point-of-activity workers attitudes towards the use of IT in construction?	S	S	P		S	S
	Why do mobile technology implementations succeed or fail?	S				P	S

3.3.1 LITERATURE REVIEW

It is fundamental to all research methods to conduct a literature review. Fellows and Liu (1999) state that in the dynamics of research, the process cycles through time, and each new research project is able to build on those which have preceded it and it is important that they do so. Therefore, it is essential that every researcher embarking on a project endeavours to discover what relevant work has already been executed, as well as what theoretical bases apply; otherwise the wheel may be invented repeatedly. Without a base of theory, there will be little understanding of what has been done and the foundation from which progress may be achieved. In summary the literature review serves to:

- define the problem;
- highlight previous research so reinventing the wheel is avoided;
- highlight methodologies that have previously been used;
- reveal gaps in previous research; and
- suggest areas for further research.

The literature review for this research project was based on academic and industrial literature dating back over the past fifty years. The initial literature review examined communication theory, site information needs, construction IT and mobile technologies. Subsequently, as new topics of relevance were encountered literature reviews were carried out for each of the areas.

3.3.2 SURVEY

A survey is a procedure in which information is collected systematically about a set of cases (e.g. people, organisations, objects). The cases are selected from a defined population and the aim is to construct a data set from which estimates can be made and conclusions reached about this population (Thomas, 1996).

Surveys can be conducted either by means of interviews or questionnaires; both of these can be structured, semi-structured or unstructured. Due to the short timescale of this element of the research project and the need to obtain a representative sample, it was decided to conduct a postal questionnaire rather than interviews, which would have been more time-consuming and therefore have limited the number of respondents. The nature of information required for this research, both quantitative and qualitative (exploratory), pointed towards the use of both structured and open questions. Further details on the survey aim and objectives, target population, questionnaire composition, method of distribution and the returns are given in Section 0.

3.3.3 USABILITY TESTING

Mobile communications is an emerging technology and its usage within the construction industry was limited when this research project began. Therefore, it was assumed that site-based personnel were not fully acquainted with hand-held computers. To understand whether they would be willing and able to use hand-held computers it was necessary to introduce a sample of site-based personnel to the new technologies and obtain their views.

It was proposed that unless current hand-held computers are found to be usable by site-based personnel then the uptake of these systems will be slow regardless of the benefits that could be available to these individuals and the project team as a whole. In order to measure this, a suitable Usability Evaluation Method (UEM) must be used.

ISO 9241-11: Guidance on Usability (ISO, 1998) provides the 'accepted' definition of usability:

"...the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use."

There are many methods used for the evaluation of usability of information and communications technology-based products e.g. cognitive walkthroughs, heuristic evaluation, usability testing and pilot testing. Different UEMs are more suitable for use in different design contexts than others. The objectives of the usability evaluation carried out for this research were:

- to find out how easy site-based personnel find these devices to use; and
- to compare several hand-held computers that were commercially available.

Due to its use of representative users and applicability to real-world situations it was determined that Usability Testing is the most appropriate UEM to use for the purposes of this research (Bowden *et al.*, 2003). Further details of the testing undertaken and the results are given in Section 4.2.2.

3.3.4 CASE STUDIES

A case study is an empirical enquiry that investigates a contemporary phenomenon within its real-life context (Yin, 1994). As shown in Table 3.1 case studies are particularly suited to answering "how?" and "why?" questions. This research project posed the questions; how can mobile technologies deliver business benefits to construction companies and why do mobile technology implementations succeed or fail?

It has also been recognized that case studies have a major role to play in increasing industry uptake of construction IT solutions (Bloomfield, 1998). They can provide industry with examples illustrating where mobile technology has been successfully adopted and details of the context, including the costs and benefits involved.

The multiple case study approach was selected because of its high exploratory potential (Yin, 1994), the limited number of example applications to study (Eisenhardt, 1989), the qualitative data required (Blismas, 2001), the focus on contemporary events, the need to study the application in its context , and the ability to provide descriptive examples for industry use (Benbasat *et al.*, 1987). The research proposition which the case studies set out to explore was:

"The utilisation of mobile technologies by point-of-activity workers in construction increases the efficiency of the process, resulting in improved data collection and hence a rapid return on investment."

Section 4.3.2 provides details of the case study protocol and the results of the studies undertaken.

3.3.5 PROCESS MAPPING

Many people have argued that construction products are one-off with each project being unique; however, the same underlying procedures and processes are adopted time and again (McConalogue, 1999). To fully understand these construction procedures and processes and to identify the opportunities to increase the efficiency of information transfer, a consistent approach must be utilised. "Process Mapping" is a management tool initially developed and implemented by General Electric as part of their integrated "Work-out," "Best Practices," and "Process Mapping" strategy to improve significantly their bottom line business performance (Hunt, 1996).

There have been many research projects investigating how to map construction processes (Baldwin *et al.*, 1999). Numerous systems are available, including Petri Nets, Warnier-Orr Diagrams, IDEF0, Entity Relationship Diagrams and Data Flow Diagrams.

A commonly referenced process model is the Generic Design and Construction Process Protocol (GDCPP). This model is based on existing descriptions of the design and construction process as well as established new product development models in the manufacturing industry including stakeholder involvement, teamwork and feedback, activity zones and hard/soft review gates (Kagioglou *et al.*, 1998). The model provides a macro level map of the entire construction process in four phases; pre-project, pre – construction, construction and post-construction. It represents a recommendation for structuring the process of delivering projects. It does not represent what actually happens currently or provide sufficient detail of the micro-level processes examined in this research.

Karhu (2000) provides a comparison of six commonly used methods: scheduling method, simple flow method, IDEF0, IDEF0v, IDEF3 and Petri Nets. He concludes that these process modelling methods have been developed for specific purposes. Therefore, a more general method is required that eliminates the difficulties associated with the process model graphical representations being too complicated for the employees involved within the process to interpret and hence make meaningful contributions.

The primary objective of the process maps that were developed was to present an illustration to industry representatives of the possible efficiency gains mobile IT could provide in order that the processes with most potential and relevance could be selected for implementation on a set of demonstration projects. Hence, in common with the conclusions of Karhu (2000) and Fleming *at al.*, (2000), it was decided that a simple graphical representation, readily understood by construction professionals, should be used. The format adopted is shown below in Figure 3.4; simply a combination of activities and deliverables (at this micro-level it is assumed that gates are not appropriate). This format has also been used to map the research design as shown in Figure 3.3. Section 4.3.3 provides details of the process mapping activity undertaken.

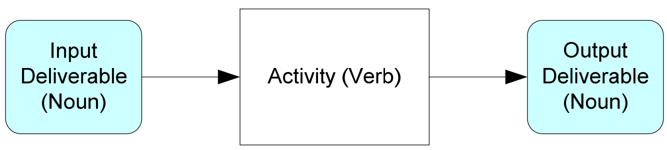

Figure 3.4 Process mapping format

3.3.6 ACTION RESEARCH

Action research is defined as an approach in which the researcher and a client collaborate in the diagnosis of a problem and in the development of a solution based on the diagnosis (Bryman, 2001). Proponents of action research state that to make academic research relevant, researchers should try out their theories with practitioners in real situations and real organisations (Avison *et al.*, 1999).

The outcomes of action research are both an action and a research outcome. It is particularly suitable for this research as it aligns with the philosophy of the Engineering Doctorate scheme, which is to undertake practical research within an industrial environment. The overarching aim is to facilitate the realisation of business benefits from the adoption of mobile information and communication technologies, both in a company and project environment.

However, in order not to unduly influence the outcomes of the demonstration projects ensuring that common areas of difficulty are discovered (and lessons are learnt which can be applied by other organisations) it was felt that the researcher should not directly participate in the taking action phase but simply record the results through semi-structured interviews and direct observations. The researcher's direct participation only occurred in the diagnosis phase, the action planning phase, solely to bring together the project team and instigate the demonstration project, and the evaluation phase (Figure 3.5).

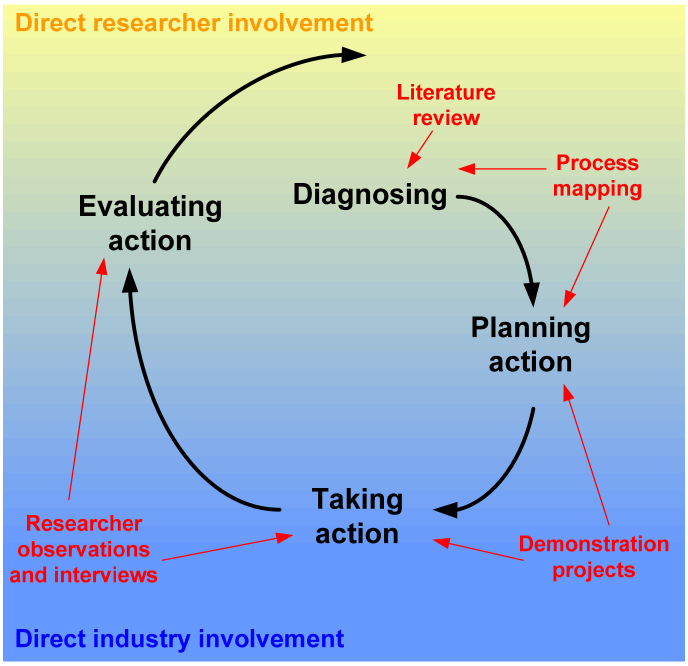

Figure 3.5 Adopted 'action research' cycle (adapted from Coghlan & Brannick, 2001)

3.4 SUMMARY

This chapter has discussed the methodology adopted for the EngD research project. It provided an overview of the framework within which the research was conducted and justified the use of a multi-methodology approach. It then provided details of the research design and the methods used.

4 THE RESEARCH UNDERTAKEN

4.1 INTRODUCTION

This chapter presents the research undertaken to meet the aim and objectives of the EngD project that were stated in Section 1.4. The research was conducted in accordance with the methodology described in Chapter 3. Where references are made to the appended papers the reader is requested to read each paper in its entirety and then return to the thesis.

4.2 PHASE 1

As stated in the previous chapter, Phase 1 of the project was undertaken to confirm that there was a need for mobile IT solutions within the construction industry and that these solutions would be accepted and suitable for use by the point-of-activity workers (e.g. foremen and site engineers). Figure 4.1 illustrates the research process that was followed; comprising a literature review, a survey and usability trials.

4.2.1 MOBILE INFORMATION NEEDS

Initially, a literature review was undertaken to identify any studies that had:

- examined the information needs of mobile construction workers;
- documented barriers to the adoption of IT within the construction industry; and
- applied mobile IT within a construction context.

Chapter 2 provides details of the literature review undertaken. Below the key areas explored in the survey are discussed.

A lack of IT literacy amongst site-based personnel is commonly cited as a barrier to the implementation of IT on construction sites (Coble & Baker, 1994, Picken, 2001). The author's experience of working on site, the general increase in the use of the Internet within people's home life and the interface similarities between a clipboard and pen and a handheld computer prompted the author to question the validity of this assertion in the context of mobile IT use at the start of the research.

It was initially thought that a literature review would reveal a recognised method for measuring IT literacy, which could be used to determine the level of IT literacy of site-based personnel. However, it revealed that 'IT literacy' is a very subjective term and will therefore mean different things to different people (Burniske, 2000, Turner *et al.*, 2000). Winship (2000) provides the following definition of IT literacy:

> *"the set of knowledge and skills needed to use information technology at a level appropriate to a person's position, work environment and discipline and the ability to continue to develop them into the future."*

Although there have been many attempts to develop an instrument to measure IT literacy, these often rely on subjective self assessment both in terms of usage and competence (Berger & Carlson, 1988).

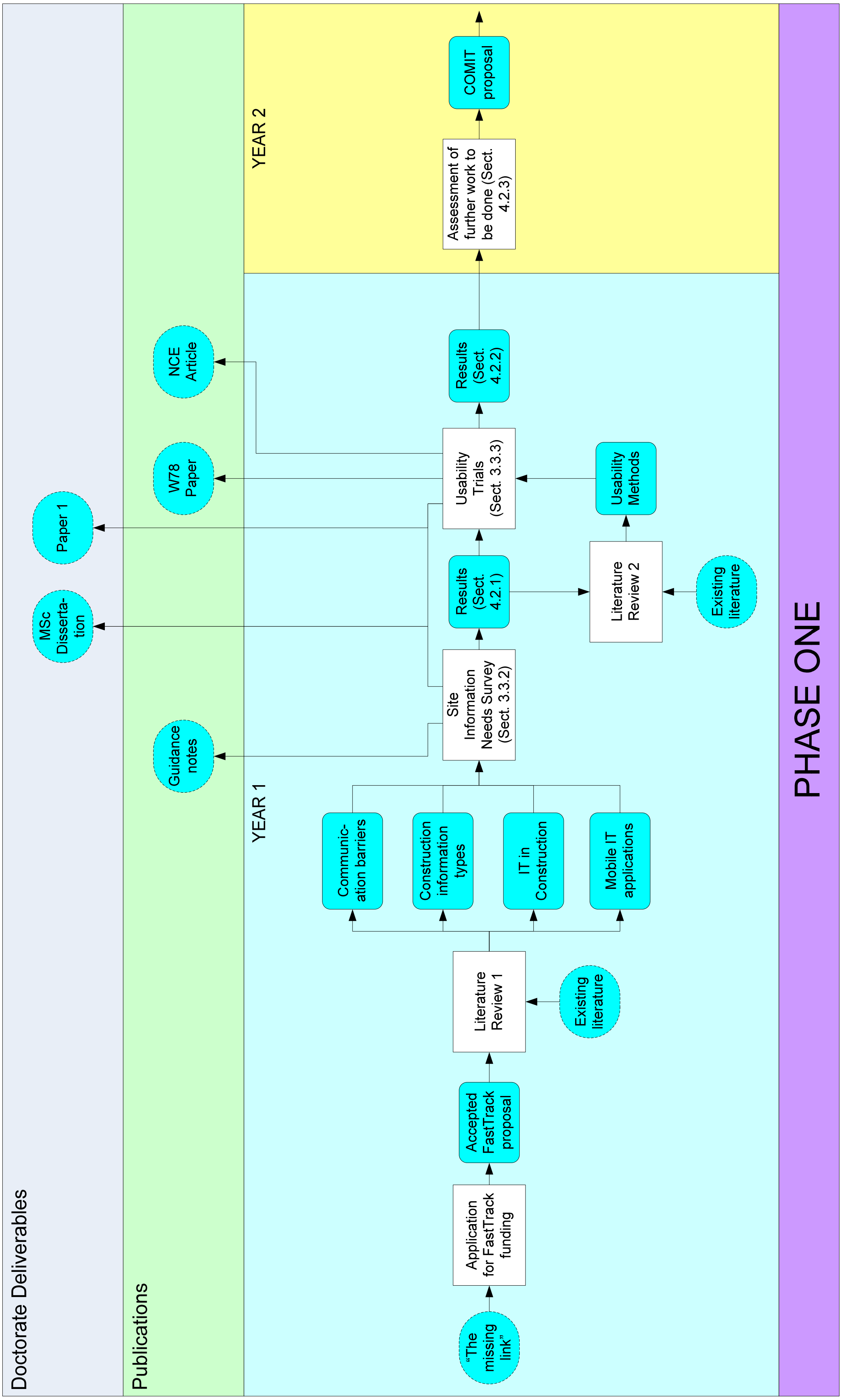

Figure 4.1 Phase 1: Research process

It was decided to undertake a survey of site-based personnel to understand the information needs of site-based personnel, which can be supported by the use of mobile IT, and to ascertain whether the current culture and skills of site-based personnel would provide a basis for successful implementation. The specific objectives of the survey were to:

- obtain a sample of respondents that are representative of the site-based personnel population;
- identify the paper-based tasks that are commonly undertaken on a construction site;
- identify the information that site-based personnel would like to have access to whilst on site;
- identify the views of site-based personnel about communications in the construction industry;
- understand the attitudes towards the use of mobile (data and voice) communications on site; and
- obtain a measure of the IT literacy of site-based personnel.

The target population for the survey were UK construction consultants or contractors who were required to carry out work in the field (e.g. resident engineers, foremen and works managers - not gangers and labourers) and who have not necessarily used a computer before.

The questionnaire used both open and closed questions. The open questions ensured that the respondent was able to provide his/her own thoughts without undue influence. It was initially reviewed by a representative of the target population and a usability consultant and then piloted with ten respondents from the target population to ensure that it was easy to complete and that the respondents understood the questions as the author intended.

The revised questionnaire, accompanied by a covering letter, which stressed the importance of completing it regardless of personal computer usage, was distributed to all personnel on the M6 Toll project (companies included Arup, Carillion, Alfred McAlpine, AMEC and Balfour Beatty) and targeted respondents through the author’s contacts within other projects (companies included Taylor Woodrow and Costain). The author’s rationale was that people are more likely to respond when requested to by someone they know. This was borne out by the relatively high response rate of 39% (78 returns) within the M6 Toll population plus more than 80% returned targeted questionnaires. Fellows and Lui (1999) suggest that for postal questionnaires the expected usable response rate is between 25% and 35%.

The results indicated that:

- the majority of respondents have direct (unshared) access to an internet connected computer at work and used a mobile phone;
- foremen and works managers have the lowest level of IT access, usage and knowledge;
- formal IT training was lacking; with respondents either teaching themselves or learning through colleagues;

- the document types that staff would find most useful to have access to/record on site were drawings, data collection forms (e.g. quality inspections), correspondence, progress information, and specifications;
- the barriers to effective communication were identified as information transfer, attitudes and protocols; and
- only a quarter of respondents had used a hand-held computer before, but the majority of respondents thought that hand-held computers could be used in construction for many tasks including data collection, viewing drawings and general communication.

The survey results, in relation to each of the survey objectives, are provided in more detail in Appendix 5.

4.2.2 VIABILITY OF MOBILE SOLUTIONS

The survey findings, outlined above, showed that hand-held computers were not yet in common use in the construction industry, although the majority of respondents thought that they could be used beneficially. The preconception of a lack of IT literacy amongst site-based personnel was no longer as relevant; with the majority of respondents having access to a PC at work and home, which they use for a wide range of applications on at least a weekly basis.

To assess whether mobile solutions were viable within the construction industry, and could address the needs identified in the survey, further research was required to understand their acceptability by site staff and to raise the awareness of the potential uses of mobile IT in construction.

As part of this research a two-day event hosted by the contractor consortium CAMBBA (Carillion, Alfred McAlpine, Balfour Beatty and Amec) was held at the headquarters of the M6 Toll project. The event consisted of two parallel activities. Firstly, a series of presentations and demonstrations were open to all site personnel throughout the two days; and secondly, usability tests were conducted on four hand-held devices by seventeen construction worker volunteers.

The aim of the usability evaluation was to compare various hand-held computers that were already commercially available and to find out how easy site-based personnel find these devices to use. The specific objectives of the usability tests were to:

- obtain a broad range of site-based personnel to act as participants;
- increase awareness of the types of portable IT devices that are available;
- identify the types of tasks that are best suited to hand-held computers;
- identify the functionality that site-based personnel would find useful;
- identify the attitudes of site-based personnel to the use of hand-held computers in the construction industry; and
- determine which device the participants preferred and why.

Figure 4.2 illustrates the usability testing procedure that was followed.

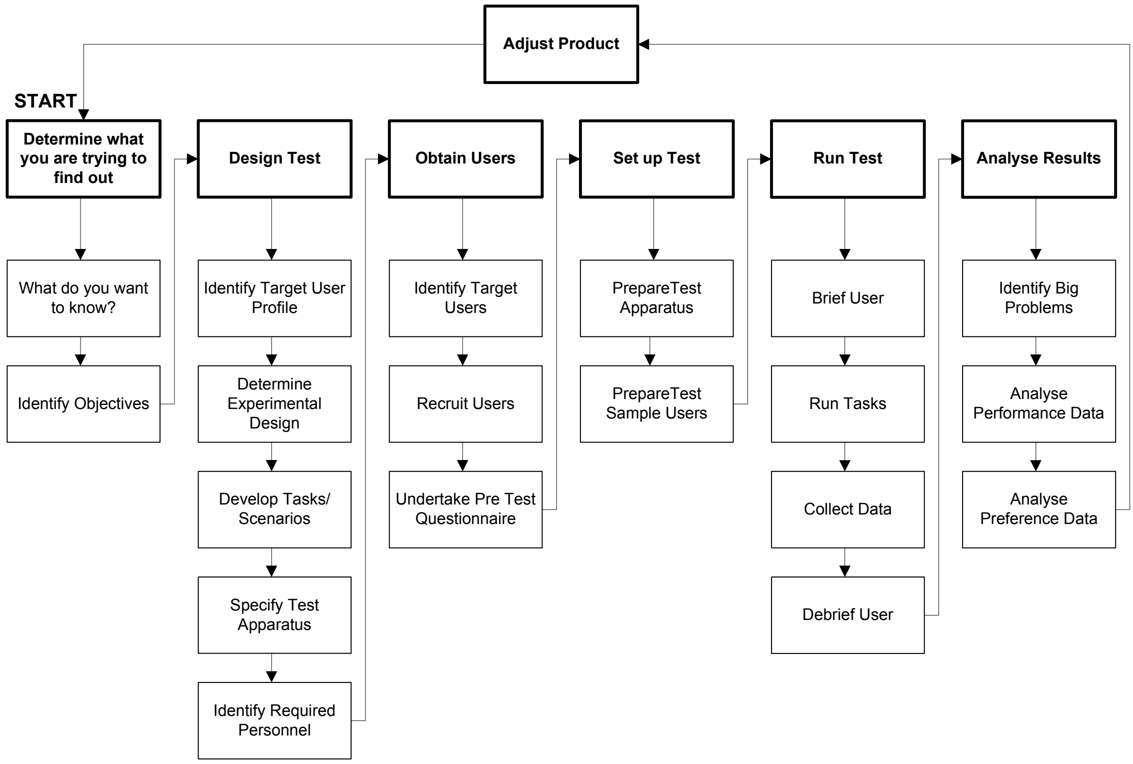

Figure 4.2 Usability testing procedure (adapted from Rubin, 1994)

Paper 1 (Appendix 1) provides an overview of the tests undertaken and the main results. To achieve the objectives outlined above, the criteria for the selection of tasks that would be carried out during the tests were as follows:

- should be representative of the tasks that site-based personnel carry out on site;
- should highlight different methods of data input and output;
- should use readily available software (financial and time constraints);
- should be able to be carried out on both the Pocket PC and Windows CE operating systems (device constraints); and
- should be intuitive and require minimal text input (literature review constraints).

Table 4.1 details the tasks that were selected to be performed in the usability tests

Table 4.1 Selected tasks

Task	% identified in survey	Data type (input/output)	Application
View a drawing	24% (Drawings)	View graphical	PocketCAD
Annotate a drawing	24% (Drawings)	Input graphical	PocketCAD
Read a method statement	15% (Documents/Reports)	View and search textual	Microsoft Reader / Word
Enter a diary note	5% (Diary)	Input textual Menu selection	Microsoft Outlook
Complete a form (Inspection Test Sheet)	12% (Data Collection Forms)	Input graphical and textual Menu selection	PocketPC Creations

Given the time and resources available to undertake the tests it was decided to limit the users to be tested to those from a single construction site. The participants were selected from those that had responded to the questionnaire outlined in Section 0 and volunteered to be involved in the trials. The information collected from these questionnaires allowed the selection of volunteers that had not used a hand-held computer before (providing an equal footing) which represented a range of ages and job-types.

Each participant received user instructions, a timeslot, and a participant questionnaire to reveal any additional details that could bias the results (e.g. right or left-handed). Each device was set up prior to the tests with the required software and files. The order of testing each device by each participant was determined by random selection. Verbal (read verbatim to ensure consistency) and written instructions (displayed on a wall) were given, describing the usability tests, how to use the devices and the procedure for each task. Each participant performed the task in the defined order. After they completed that task they filled in the relevant question sheet. Once everyone had finished, the next task was described. No conferring was allowed, although questions could be directed to the test supervisor. Once all five tasks were completed, the participants received the next device. To ensure that the order in which the participants received the devices varied, an appropriate swapping mechanism was used. Once each participant had performed all five tasks on each of the four devices a videotaped discussion was held to obtain further qualitative data.

Although, time, cost and accessibility of end-users were all factors that resulted in this testing having a sample that was too small to provide statistics that could be generalised to the target population, Usability Testing proved to be a very useful method for evaluating the usability of mobile IT devices in a construction context. Through the involvement of representative users an understanding of the usability of the product by its end users in the workplace was gained. The results from this sample illustrated that there were no significant differences across job type in either preference for using the device or satisfaction with using the device. Also, previous hand-held computer and IT experience did not significantly affect the satisfaction scores for using the devices. The majority of the participants (88%) would be happy to use a hand-held computer on site, typical comments were “Superb”, “Very powerful”, “Definitely see an advantage”. However, the barriers of cost and training tempered these comments, and many participants reiterated the need for proof that the devices would be cost effective, and that usable, useful applications would be available.

4.2.3 PHASE 1 CONCLUSIONS

4.2.3.1 Barriers to the uptake of mobile IT

The literature review, survey and usability trials all provided insight to the barriers that would need to be overcome in order to increase the adoption of mobile IT in the construction industry. In addition to barriers specific to the use of mobile IT, it is assumed that the barriers to the mainstream uptake of mobile solutions in construction are those commonly cited as barriers to the uptake of construction IT solutions in general, namely; the low level of perceived benefits from IT investments amongst construction business managers (Andresen *et al.*, 2000), the process of investment justification (CIRIA, 1996) in an industry with generally low profit margins, a lack of awareness about information and communication technologies (Love & Irani, 2001) and the lack of exemplars demonstrating its successful use by others (Anumba, 1998). These barriers can be categorised into financial, technical, procedural, cultural and usability barriers as shown in Table 4.2.

Table 4.2 Barriers to the adoption of mobile IT in construction

Barriers to the adoption of mobile IT in construction				
Financial	**Technical**	**Procedural**	**Cultural**	**Usability**
The costs involved in purchasing a device could outweigh the benefits gained. At approximately £1200 for a rugged device, many participants in the usability trials thought that management would have to be convinced that purchasing these devices was worthwhile.	If the device broke down, all of the work that had been carried out since the last synchronisation could be lost.	The usability trial participants thought that personnel might become too reliant on the device, such that if it were to break down they would have to go back to pen and paper and the necessary protocols would no longer be available.	Attitudes towards the devices and I.T. in general could be a barrier, one participant in the usability trials commented "Ought not to underestimate people, could just pick up a telephone instead…".	The usability trial participants thought that the stylus was too small to handle with larger hands and potentially having to wear gloves too.
The low level of perceived benefits from IT investments amongst construction business managers (Andresen et al., 2000).	The usability trial participants thought that battery life should be considered. With staff working a 10-12 hour day in the summer, the inconvenience of running out of battery power whilst out on site could create reluctance to rely on the device.		The devices were perceived by some participants in the usability trials as a gimmick or a toy, and it was thought that they should only be used when appropriate rather than as standard.	The usability trial participants thought that the screen size of hand-held computers was impractical for viewing drawings, and many would prefer to stick to A2 paper copies to carry out drawing-based tasks.
The process of investment justification (CIRIA, 1996) in an industry with generally low profit margins.	Perceived lack of suitable devices – 50% of the survey respondents, that did not think that hand-held computers could be used on site, thought that they would not stand up to the harsh site environment.		A lack of awareness about information and communication technologies (Love & Irani, 2001) and the lack of exemplars demonstrating its successful use by others (Anumba, 1998).	Manual data input using either the stylus or the pop-up keyboard was found, by the usability trial participants, to be time consuming. This indicates the need for manual input to be minimised through the use of drop-down menus and pre-written text.
			A lack of IT literacy amongst site-based personnel is commonly cited as a barrier to the implementation of IT on construction sites (Coble & Baker, 1994, Picken, 2001)	

4.2.3.2 Benefits of the uptake of mobile IT

In spite of the barriers summarised above, the usability trials showed that there was generally a good level of enthusiasm for the future use of hand-held devices on a construction site. This is illustrated by the benefits that the participants identified during the trials:

- the information is less subjected to the elements, unlike paper, which can get wet and blows around in the wind;
- the information is easy to carry, rather than having a lot of paperwork 'filed' in the back seat of the pick-up truck;
- the tedious task of typing up notes carried out at the end of the day when back in the office is eliminated by collecting data electronically in the field and then synchronising it back to the site data network;
- it could provide a useful reference tool so that site personnel do not have to remember or predict what information they will need to view/record in the field;
- it could enable engineers to spend more time actually out on site; and
- data collected in the field will be more structured and consistent.

There are also further benefits for the project team as a whole that result from having instant access to well-structured data:

- information collected in the field can be immediately passed on to other members of the project team;
- the data can be imported into, and manipulated, using other software packages; and
- the data can be easily searched in the future, both for auditing purposes and for future knowledge management applications.

4.2.3.3 Further work required

This work has illustrated that many of the perceived barriers to the uptake of handheld devices in construction are either non-existent or can be relatively easily overcome. However, there are currently very few construction teams realising the full potential of their use.

To facilitate the appropriate uptake of mobile IT, overcoming the barriers to realise the benefits, it was important to ensure industry participation in the next phase of the research. To achieve this, COMIT, Construction Opportunities for Mobile IT, was formed as a DTI, Partners in Innovation, supported project. A major element in the project was the formation of the COMIT community which consists of representatives from the key stakeholders:

- Construction and engineering companies
- Technology providers
- Research and development institutions
- Dissemination companies (e.g. publishers and trade associations)

The community, which comprises fifty different organisations, provided guidance and input to the deliverables, making sure the research undertaken provided what was needed. The primary objectives of COMIT were to:

- document existing applications of mobile IT in Construction;
- create a better understanding between technology and construction companies;
- understand which applications will deliver business benefits; and
- create wider awareness of the benefits of mobile IT in construction.

The activities undertaken as part of COMIT to fulfil the requirements of the doctorate research are outlined in Phase 2 below.

4.3 PHASE 2

As stated in the previous chapter, Phase 2 of the project was undertaken to identify suitable processes for the use of mobile IT solutions and understand, and quantify where possible, the variables that would influence their successful adoption. Figure 4.3 illustrates the research process that was followed; comprising a state of the art assessment, case studies, process mapping and the demonstration projects.

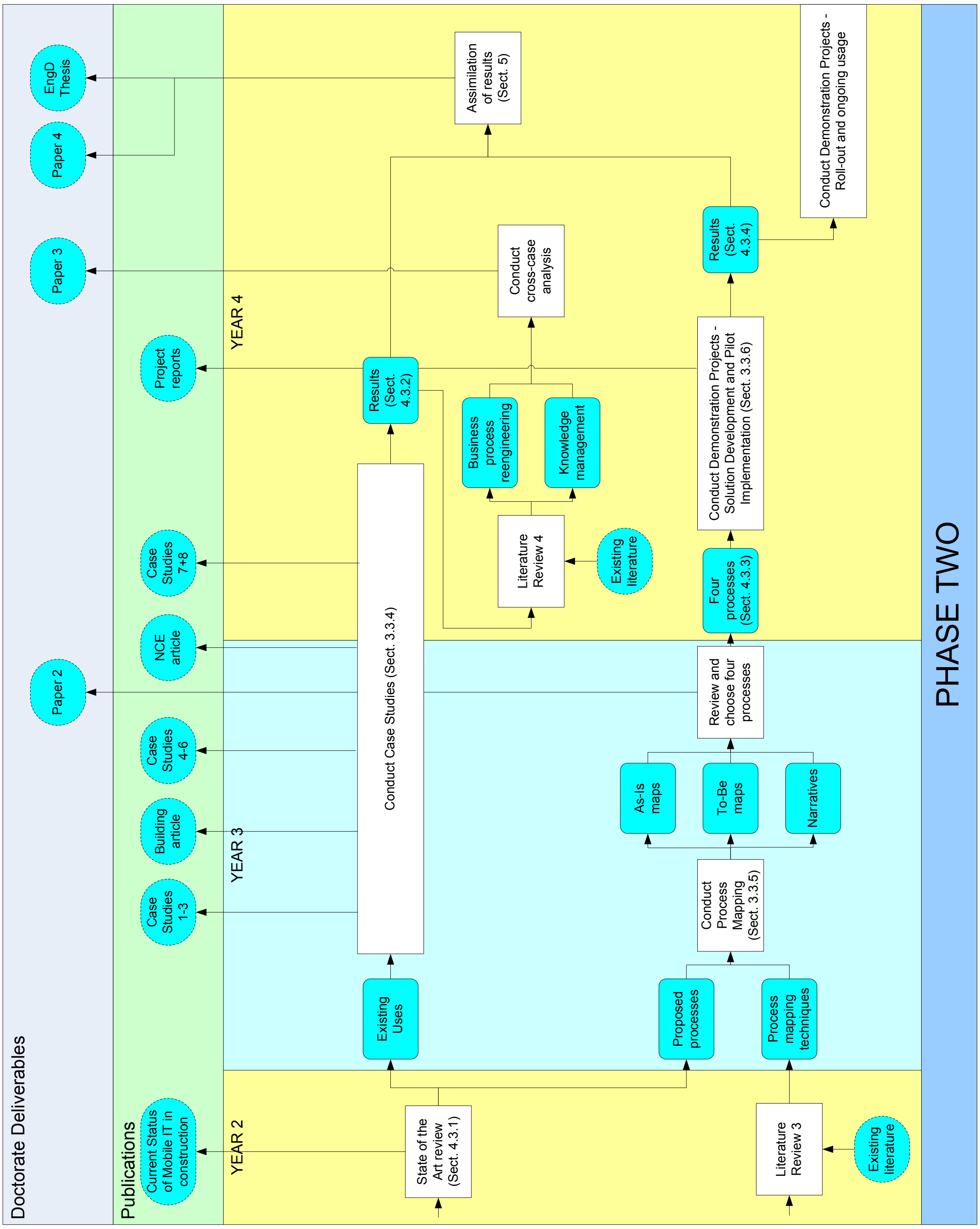

Figure 4.3 Phase 2: Research process

4.3.1 STATE OF THE ART ASSESSMENT

The literature review undertaken in Phase 1 of the research and the resulting guidance notes produced for the DTI were incorporated into a state of the art assessment of the use of mobile IT in the construction industry. This included details of the mobile hardware, software and infrastructure available for use in the construction industry; a summary is provided in Paper 1 (Appendix 1). Table 4.3 summarises which hardware is already in use for which applications.

Table 4.3 Mobile hardware usage

		Hardware							
		PDA	Smart phone	Hand-held computer	Tablet PC	Digital pen and paper	RFID tags	Barcodes	Digital hard hat
Current use	Inventory	Y	Y			Y		Y	
	Snagging	Y				Y			
	Timesheets	Y		Y		Y			
	RFI	Y				Y		Y	
	Daily reporting	Y		Y		Y			
	Plant tracking				Y		Y	Y	
	Materials tracking						Y	Y	
	Inspections	Y			Y	Y			Y

Two further elements were included in the report:

- synopses of a range of projects that were already using mobile IT: the "existing uses". These examples were found through the literature review and industry consultation and can be viewed at www.comitproject.org.uk.
- a list of processes which might be suitable candidates for improvement through the use of mobile IT.

4.3.2 CASE STUDIES

It has been recognized that case studies have a major role to play in increasing industry uptake of construction IT solutions (Bloomfield, 1998). They can provide industry with examples illustrating where mobile technology has been successfully adopted and details of the costs and benefits involved.

The research proposition which the case studies set out to explore was:

"The utilisation of mobile technologies by point-of-activity workers in construction increases the efficiency of the process, resulting in improved data collection and hence a rapid return on investment."

The state of the art review detailed in Section 4.3.1 acted as the initial screening process for the selection of appropriate case studies. An "existing use" was prepared for each proposed case study. This set out the business problem and solution, details of the hardware and software used and the project location. The list of "existing uses" was reviewed and six were selected for full case study development. These were chosen on the basis of a UK location, and to provide a variety of processes and technologies.

In addition, the opportunity to explore two cases of the use of mobile telephone applications in Finland was presented by VTT (including one that was only partially successful), and three cases of the use of mobile IT within Arup were also investigated as these provided one "unsuccessful" case and two studies utilising different technologies; GPS in combination with a PDA application and BlackBerry. Paper 2 (Appendix 2) provides further details of the case studies undertaken for this research.

All of the applications explored through the case studies achieved process improvement by eliminating non-value adding activities, capturing information once only at the source, and/or automating certain activities. However, the process improvements achieved in the unsuccessful cases were not sufficient to offset the costs incurred. This was due to the lack of volume of information collected and the difficulty in entering the information required, which stemmed from a lack of understanding of the initial process and/or the users' needs. If a process evaluation and business case had been undertaken, prior to solution development, it would have shown that mobile IT did not provide a commercially viable solution. The successful cases covered a wide range of processes, all of which were collecting structured data and in each case return on investment was achieved in less than twelve months.

In order to achieve a successful implementation and hence a rapid return on investment the following lessons can be learnt from this study. It is important to:

- have ongoing involvement of a senior executive to champion the use of the technology;
- have early involvement of the users to fully understand their needs and develop a sense of ownership of the solution;
- undertake upfront process analysis to understand the data collection requirements;
- choose the most suitable user-interface, and thence the device, for the users' data collection and retrieval activities;
- develop a solution with a short learning curve; and
- provide sufficient training and ongoing support.

4.3.3 TARGETED IMPLEMENTATION

The results of the case studies detailed above in Section 4.3.2 indicated the importance of choosing an appropriate process to apply mobile IT to. For a system to be economically viable, the cost savings must be sufficient to justify the investment concerned and pay back the investment within a realistic time-span, given the technology involved and the business environment concerned (Baldwin *et al.*, 1994). It is therefore imperative to fully understand the process which is proposed for the application of a mobile solution and to estimate in advance the improvements that could be made. This will help ensure that mobile IT developments only proceed for appropriate processes; which will in turn ensure an acceptable return on investment.

This state of the art assessment identified thirty processes involving point-of-activity workers that could potentially be improved through the introduction of mobile IT. These processes were reviewed by industry representatives and ten selected for more detailed investigation:

- Goods received notes
- Drawing distribution and usage
- Task allocation
- Monitoring progress
- Monitoring health and safety on site
- Quality inspections
- Site design problem resolution
- Site diaries
- On-site accounting of operatives/visitors
- Maintenance inspections

Paper 3 (Appendix 3) provides details of the process mapping activity that was undertaken for each of these.

Mapping the "As Is" processes provided the research team with a sound basis on which to determine the "To Be" processes. Mapping each activity and deliverable and highlighting the areas for improvement enabled ideas for the "To Be" process to be developed, often resulting in unforeseen improvements. The technologies proposed for each process together with their benefits and drawbacks are shown in Table 4.4.

The positive knock-on effects of implementing a mobile IT solution were much more clearly identifiable and also enabled the identification of common deliverables and personnel across the ten processes.

The industry representatives found the process maps and associated narratives very helpful; providing them with a justification for exploring mobile IT solutions. It was recognised that these generic process maps could be applied with minimal customisation within their organisations, thus reducing the time taken up front to understand the process.

Table 4.4 Technologies proposed for use in the selected processes

(DC – Data Capture, I – Identification, C – Communication)

	Mobile IT	Processes Identified	Benefits	Drawbacks
Devices	**PDA**	Monitoring progress (DC) Monitoring health and safety on site (DC) Quality inspections (DC) Task allocation (C) Goods received notes (DC) Site design problem resolution (C) Site diaries (DC) Maintenance inspections (DC)	Enables structured data collection through drop-downs and field verification. Can be used to receive relevant information and updates. Regularly used fields can be automatically completed such as date, time, project name, user details. Can collect data through periphery devices such as a camera or a barcode reader. Can prompt for information to be recorded and will not allow completion until this is done.	The form factor makes it unsuitable for viewing large format information e.g. drawings. Unstructured information is time-consuming to enter using the virtual keyboard or the stylus.
	Digital Pen and Paper	Monitoring health and safety on site (DC) Site diaries (DC)	Very easy to learn to use as it is just like a traditional pen and paper. More suited to collecting unstructured as it is just like writing.	Only data collection is possible; no facility for delivering information to the field.
	Tablet PC	Drawing distribution and usage (C) Task allocation (C)	The form factor makes it more suitable for viewing large format information e.g. drawings. Enables structured data collection through drop-downs and field verification. Can be used to receive relevant information and updates. Regularly used fields can be automatically completed such as date, time, and user details. Can collect data through periphery devices such as a camera or a barcode reader. Can prompt for information to be recorded and will not allow completion until this is done.	The larger form factor makes it more difficult to carry and requires two hands to operate. Significantly more expensive than the other devices listed here.
	Auto-ID	Drawing distribution and usage (C) Monitoring health and safety on site (DC) Goods received notes (DC) On-site accounting of operatives/visitors (I) Maintenance inspections (DC)	Simple to use to track documents, materials, equipment and people and their associated information e.g. training records.	Although a tag is relatively cheap, one tag is required for each and every item that you wish to track accumulating expense. Uncertainty of whose responsibility it is to tag items; who pays versus who gets the benefits.

Devices	Mobile phone	Drawing distribution and usage (C) Quality inspections (DC) Goods received notes (DC) Site design problem resolution (C) Site diaries (DC) On-site accounting of operatives/visitors (I)	Already an accepted technology for use on site. SMS can be used to send simple alerts and capture yes/no type responses. No need to provide the workforce with new equipment as most will have a mobile phone already.	Limited functionality and screen size.
	GPS receiver	Monitoring progress (DC) Maintenance inspections (DC)	Automatic capture/delivery of information enabled through identifying the location of the user.	Accuracy limited to a few meters unless you use differential GPS which requires the installation of a base station; increases accuracy to within a metre.
	ePaper	Drawing distribution and usage (C)	The form factor makes it more suitable for viewing large format information e.g. drawings. Requires very limited power.	Not currently commercially available.
Communications infrastructure	WLAN	Drawing distribution and usage (C) Monitoring health and safety on site (DC) Task allocation (C) Site design problem resolution (C) On-site accounting of operatives/visitors (I)	Information downloaded as and when required, limiting the need for device storage capacity. Helps to ensure the latest information is being used. Contemporaneous information can be immediately distributed. Provides a higher bandwidth than GPRS or 3G making it more realistic to transfer larger files. Can be used to provide limited accuracy location information. Data transfer is free once the system is set up.	Requires WLAN base stations to be installed to cover the site. Water and metal interfere with its transmission.
	GPRS/ 3G	Monitoring health and safety on site (DC) Task allocation (C) Site design problem resolution (C) On-site accounting of operatives/visitors (I) Maintenance inspections (DC)	Information downloaded as and when required, limiting the need for device storage capacity. Helps to ensure the latest information is being used. Contemporaneous information can be immediately distributed. Can be used to provide limited accuracy location information.	Bandwidth is less than that provided by WLAN so file transfers files will take longer. Charges are made in accordance with the amount of data transferred.
	Synchro nisation	Monitoring progress (DC) Quality inspections (DC) Site diaries (DC)	No additional costs for data transfer.	Have to return to the site office in order to transfer data.

4.3.4 DEMONSTRATION PROJECTS

The demonstration projects were instigated to provide the COMIT project participants with a chance to put the research undertaken into practice and to provide an appealing dissemination mechanism to encourage wider industry uptake. They also provide the opportunity for further corroboration of the research results and more in-depth data collection.

For the purposes of this thesis, only the initial phases of solution development and pilot implementation are considered. A fuller understanding of these stages is of particular importance to complete this research, since they provide the researcher with the opportunity to observe and document these crucial stages in detail as they progress; rather than retrospectively as in the case studies outlined in Section 4.3.2.

4.3.4.1 Process selection

The “As Is” and “To Be” process maps and the associated narratives (detailed in Section 4.3.3), produced to evaluate the potential improvements made possible by mobile IT, were reviewed by industry representatives. Four processes, which they believed had the most potential for improvement, were selected to be implemented on the demonstration projects:

- monitoring progress;
- monitoring health and safety on site;
- site design problem resolution; and
- maintenance inspections.

Members of the COMIT community were asked to volunteer to undertake the demonstration project for each of these processes (see Table 4.5). A kick-off meeting was held in April 2004 to introduce the project teams and elect a project champion. Subsequently each team acted autonomously with the researchers undertaking independent observations. The following sections summarise the initial phases of solution development and pilot implementation for each demonstration project and highlight the lessons learnt.

Table 4.5 Demonstration project teams

Process	Contractor	Software developer	Hardware
Monitoring progress	Pearce Group Limited	Mobile Computing Systems Limited	Symbol SPT1846
Monitoring health and safety on site	Pearce Group Limited	Knowledge Online Limited and Sysnet	Fujitsu Pocket Loox 610 Fujitsu Pocket Loox 720 Compaq i-mate Logitech Digital Pen
Site design problem resolution	Stent Foundations Limited	Data Mobility Limited and Orange	Orange M1000
Maintenance inspections	Taylor Woodrow	TBS Systems Limited	Orange M1000 Orange M2000

4.3.4.2 Monitoring progress

Pearce Group Ltd. is a medium sized main contractor based in the south-west of the UK. They recognise the importance of good supply-chain relationships and actively apply a "collaborative team" approach. In recent years they have adopted the Last Planner System advocated by Ballard (2000); on one project this enabled them to reduce a nineteen week programme by seven weeks. The stages of the Last Planner System that Pearce have adopted include: the collaborative planning workshop and weekly progress meetings which are detailed here.

The collaborative planning workshop is held prior to project commencement. Representatives from all the main project suppliers participate in the workshop to develop and agree the master programme and the programme for each phase of the project. By bringing all the major players together early in the project critical interdependencies can be discussed, assumptions tested and best practice agreed on.

The programme is developed using a series of post-it notes representing one day's, or less, work for a team (each sub-contractor has a different colour) which are stuck onto a large wall in a traditional programme sequence. These are then manipulated by the participants to further optimise the programme (see Figure 4.4). It is a very hands-on workshop, with interaction between the participants being essential.

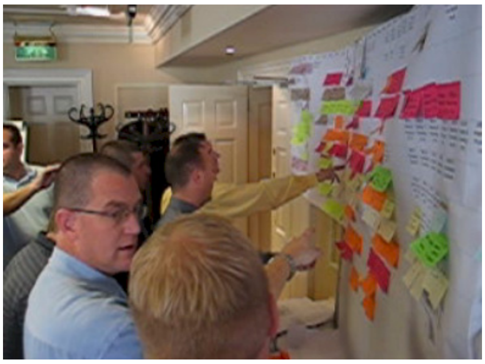

Figure 4.4 Collaborative planning workshop

The weekly progress meetings are conducted on site, again with representatives from each sub-contractor. The purpose of the meeting is to review the work completed to date and to plan the work that will be done in the next period. The reason for any delays are recorded and the plan percent complete (PPC) is calculated; this provides benchmarking information to monitor project progress against other similar projects and monitor sub-contractor performance. This provides the material required to support continuous improvement initiatives.

Although these processes are producing significant benefits they require a lot of administration time. For example:

- the time taken to produce an electronic project programme from the post-it note representation completed on a wall is estimated as two to three weeks; and
- much of the weekly progress meeting is simply spent collating the work completed to date rather than discussing how to improve on the progress made.

Pearce had already had experience of the benefits that mobile solutions can provide when they worked with Mobile Computing Systems (MCS) to develop a hand-held solution for conducting snagging inspections. They were therefore very open to discuss the current process with MCS and brainstorm potential improvements that could be made possible through the use of mobile IT. MCS were also invited to attend a collaborative planning workshop and a weekly meeting to see these processes in action.

Following these discussions a specification for the mobile solution was developed by MCS and subsequently approved by Pearce. The solution proposed consists of three modules. The first module addresses the collaborative planning workshop. Instead of handwritten post-it notes each day's activity is printed out as a 'task ticket' using a workshop management console. The workshop administrator selects the trade, the contractor name and enters the task description. The system then records the task details in the system database and prints a task ticket that is colour coded by trade, and contains the contractor name, the task description and unique barcode identification. The system prints a bar-coded day card that is used as the day column headers and the task tickets are then arranged below the appropriate day column header card and the project task timing chart assembled in the normal way (Figure 4.5). When the chart is complete the workshop administrator uses a barcode reader to scan the tickets, starting with the day card and working down the column. This process is repeated for each column on the chart until all tickets have been scanned. All of the data is recorded into the database and can immediately be reproduced and shared with other parties.

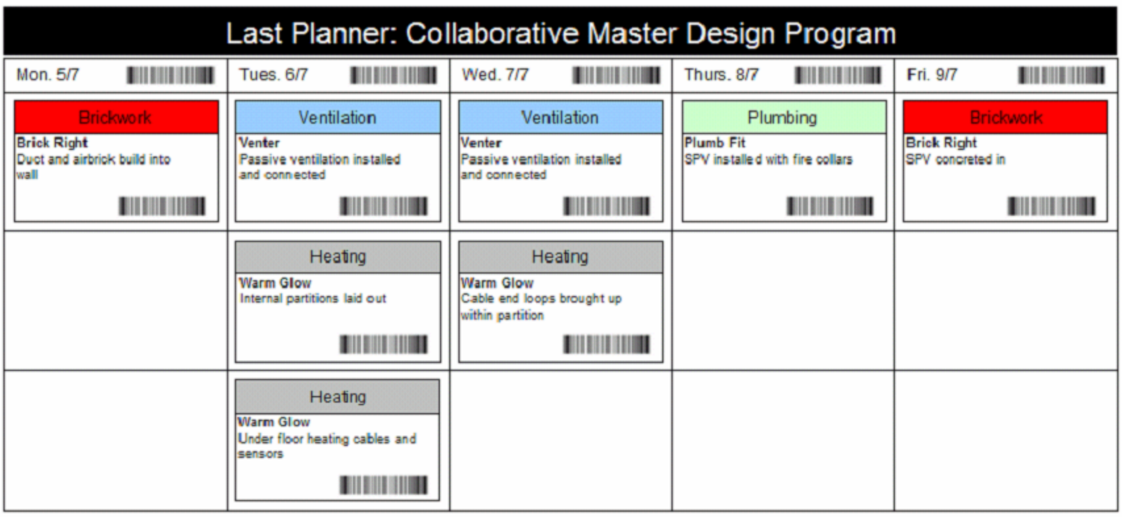

Figure 4.5 Mobile solution for the collaborative planning workshop

The second part of the solution allows the sub-contractors to enter their progress to date, using the site management console, during the week prior to the weekly progress meeting. Then at the meeting itself the relevant section of the programme is produced for discussion and to confirm the next week's tasks. At the end of the meeting the system prints the revised weekly work plan (WWP) for each site contractor.

The final part of the solution allows real-time data collection from the sub-contractors. The WWP is delivered directly to the sub-contractor's mobile computing device. They are able to review the WWP data on the handheld, record WWP fulfilment, enter reasons for delay selected from a standard list, as well as review a high level summary and KPIs for the project.

The system is designed to maintain the benefits of the collaborative workshops and the weekly meetings but remove the needless data re-entry and provide up-to-the-minute information. The solution was implemented on site in July 2005.

4.3.4.3 Monitoring health and safety on site

This demonstration project was also hosted by Pearce Group Ltd. Pearce volunteered to pilot a health and safety inspection PDA-based solution provided by Knowledge Online (KOL) and to explore how the digital pen and paper solutions provided by Sysnet could be utilised.

Pearce operates a small central health and safety department. At the outset of a project they determine how often they need to perform detailed H&S inspections in accordance with the type of project and the risks involved. To supplement these inspections someone on site will be given responsibility for day to day health and safety. Pearce's H&S manager is keen to have more regular formal site inspections and to delegate responsibility for these to someone on site.

KOL had developed a PDA-based H&S solution and were keen to pilot this with Pearce to understand more fully what factors influence its successful adoption. The solution was demonstrated to the H&S manager and a site foreman who immediately saw its potential:

- site staff could undertake structured H&S inspections and the details would be immediately available to the central H&S department, enabling more regular inspections;
- trends showing reoccurring hazards can be spotted not only within single projects but across all Pearce's projects and their sub-contractors; this enables preventative measures to be put in place and potentially reduce accidents and the time and costs these involve;
- the information gathered and resulting trends can be easily shared with Pearce management and the project clients; this can show Pearce as a responsible company increasing client confidence; and
- the roaming H&S inspectors can access the H&S information from anywhere; this enables them to set out to their inspections immediately from home rather than having to go into the office first to collect information they need.

In parallel with this Pearce wished to pilot a digital pen and paper solution. It was determined that the hot-works permit would provide a good demonstration of its capabilities. This form needs to be completed every time hot works are undertaken and signed off once the works are completed. The completed form has to be kept for the duration of the project. A digital paper form was developed which looked exactly like the original paper form.

The pilots of both solutions began in November 2004 on 'Project Orange' construction of a juice factory for Gerber Foods in Bridgwater (Figure 4.6 and Figure 4.7). Initial interviews and observations show that after initial teething problems, mainly technical, the solutions are well accepted and being used. The initial problems included:

- compatibility of the KOL software with the Fujitsu PDA provided; this has been overcome by moving to a Compaq i-mate;
- the initial KOL interface provided nearly 300 questions, making it difficult to use; this has been overcome by providing a shorter interface for the site H&S coordinator to use consisting of only 20 key questions;
- usability issues were resolved by KOL being in frequent communication with the H&S manager and the site coordinator; and
- the WLAN, for use with the KOL solution, installed within the portacabin is only accessible within a 5m radius, Pearce are currently exploring these difficulties.

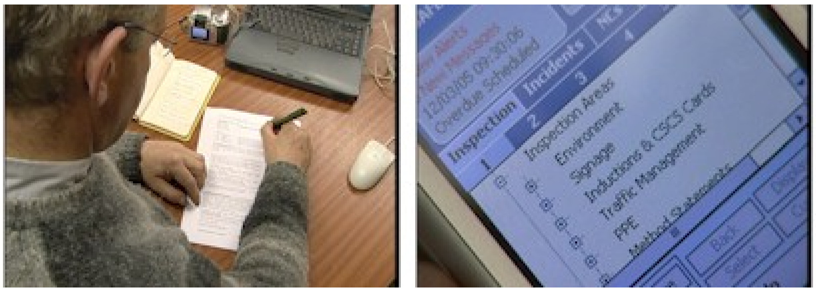

Figure 4.6 H&S inspection; before and after

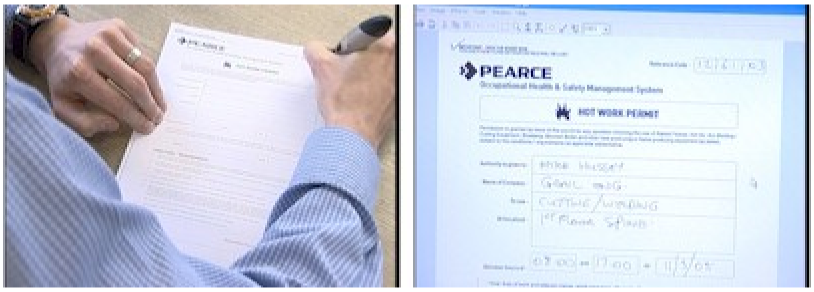

Figure 4.7 Hot works permit solution

There have been no problems with the digital pen solution, as it operates just like a normal pen and paper. The only difference is that the digital pen has to be docked to allow it to synchronise with the database where the digital forms are stored. The acceptability of the digital pen solution is evidenced by the fact that the site foreman is now using the pen to take meeting minutes and to send sketches on to other parties. The pilots will conclude in October 2005.

4.3.4.4 Site design problem resolution

Stent Foundations Ltd., a subsidiary of Balfour Beatty, is a leading specialist in ground engineering in the UK. Their interest in improving the way they work through utilising emerging technologies is evidenced by their Stent Integrated Rig Instrumentation System (SIRIS) and Stent Handheld Electronic Piling Assistant (SHERPA) systems which utilise on-board computers, tablet PCs and WLAN to collect information from, and deliver information to, the piling gangs in the field (Ward, 2004). Stent were interested in providing their site engineers with a system that would help them to communicate problems encountered in the field back to Stent head office. Traditionally this is carried out through a phone call or more formally through a request for information (RFI) or a non-conformance report (NCR). Typical difficulties encountered in this process are:

- the office-based person will often only have drawings representing the finished structure and hence will have difficulty in envisaging the current situation on site;
- there may be other issues on site that prevent the office-based person's solution from being realised e.g. the equipment required for the solution is not suitable or unavailable;
- the formal process from problem discovery to solution is often very slow; requiring a reporting hierarchy to be followed. This may also result in a 'Chinese whisper' effect where the problem description that the office staff gets is unrelated to the actual problem;
- the solution proposed may be based on inaccurate information and could result in even more problems;
- the office-based staff may have to travel to site to get a full understanding of the problem; this will entail significant time and costs being accrued; and
- miscommunication can result in ill-feeling between site and off-site staff which in turn makes the situation worse.

Although this process has been addressed by past research through the use of the digital hard hat (Liu, 1995) it was felt that currently available mobile devices offered enough functionality to satisfy the need for sufficient multi-media information to be transferred back to the office and that these would be more readily accepted by site staff.

Stent's site engineers may work on multiple sites and so, after a review of available hardware, it was decided that a highly portable device like a PDA should be used. Mobile phones were also explored; however, the current functionality was not sufficient. An Orange M1000 was chosen by Stent and although the ability to capture photographs, notes, sketches and voice was possible it was felt that a more structured application needed to be developed to enhance the usability of the solution. Data Mobility (DM) volunteered to develop a PDA based solution for this process. Following discussions with Stent, it was decided that neither the RFI nor NCR process should be incorporated into the solution as most projects will already have systems that provide this process. Instead, the solution should be self-sufficient and simply collect a multi-media package of information that could then be associated (through a hyperlink) to whichever system and reporting process was in use by the project.

The Arsenal stadium project was selected for the pilot; however, DM's computers were hacked whilst the solution was being developed. This resulted in the solution being delayed such that, once it was ready to pilot, Stent had only three weeks left on the construction project which was not sufficient time to observe and gain realistic results. Another project was sought, but when this was due to start on site it emerged that DM were having difficulties with their private investors and were no longer able to provide the solution to Stent. Their investors wanted DM to focus on providing Tablet PC solutions and no longer provide solutions for the PDA. A Tablet PC solution was not acceptable to Stent and so DM were asked to reconsider their stance and stick to their obligations to the demonstration project. Initially DM agreed, however, shortly afterwards they were taken into receivership. It was decided with the short time-scales left for the demonstration project that the standard software provided with the M1000s, Office Freedom, would be used. Although not perfect, this will provide an insight into what is possible with an off-the-shelf solution. Two PDAs with the Office Freedom software began pilots on site in June 2005.

4.3.4.5 Maintenance inspections

Taylor Woodrow Facilities Management (TWFM) is a trading division of Taylor Woodrow Construction Ltd. They provide facilities management (FM) services to a range of clients. This demonstration project reports on a pilot that was already planned for providing the FM services to Shell petrol stations nationwide. Taylor Woodrow coordinates the activities of hundreds of mobile repair technicians (MRTs) who travel to client sites to provide FM services (Figure 4.8). The use of mobile technology to provide the MRTs with work orders and the ability to submit maintenance reports remotely was suggested by the MRTs themselves to eliminate the need to complete paperwork in their evenings.

Figure 4.8 MRT unit

The original process entailed the client phoning the call centre to report work to be completed and the call centre then phoning or emailing an MRT to allocate the work. The MRT would record all details of the work undertaken in his A4 diary and then spend one evening a week catching up with paperwork and e-mails to and from Maximo, the central FM system. It has been estimated by the MRTs that they spend five hours a week downloading forms and other information from the Maximo system in the evenings to their laptops.

TWFM have employed TBS, a mobile solution provider, to integrate their TaskMaster field service automation solution with TW's existing FM system, Maximo. Initial trials began in January 2005 with four MRTs and this pilot was extended in March 2005 to twenty MRTs. Although everything is proceeding as expected, reporting on this demonstration project is currently restricted by TWFM; hence results will not be available until later this year.

4.3.4.6 Lessons learnt

This section provides an outline of the lessons learnt, from the development and initial implementation phases, across the demonstration projects (these are in addition to those given in Section 4.3.2):

- Construction companies should be prepared to identify several possible pilot projects to make provision for any delays in the completion of the software development. This can result in a much larger delay in the pilot, if the construction project that was initially selected for the pilot has already commenced and has progressed too far to incorporate a new solution. In one demonstration project this resulted in a three month delay;
- Construction companies should be aware that the start dates and actual commencement of the construction project selected for the pilot may change. In one demonstration project the selected client decided to put all of their construction projects on hold, hence another suitable project for the pilot had to be found resulting in the pilot being delayed by six months;
- When selecting a solution, it is advisable to consider the software provider's hardware recommendations as this should ensure compatibility. Although according to the specifications the software and hardware selected by the contractor should be compatible, this may not be the case and additional work will be required to ensure a working solution;
- When adopting an existing solution, time should be incorporated into the pilot programme to enable the solution to be adapted to the actual end-users' requirements if required;
- The solution provider should be carefully selected and their corporate stability taken into account. The benefits of choosing a small bespoke solution provider will be lost if they are unable to complete the work.

4.4 DISSEMINATION

Wide dissemination of the results is essential to achieve this project's aim: *"to facilitate the realisation of business benefits from the adoption of mobile information and communication technologies"*. This has been achieved through the development of a website, a series of presentations at conferences and articles in the trade press. These publications (as shown in Figure 3.3) are available at www.comitproject.org.uk.

4.5 SUMMARY

This chapter discussed the research undertaken to meet the aim and objectives of the EngD project. It also highlighted how the results from each research activity were used in subsequent activities and provided an overview of the results of each stage. The conclusions which can be drawn from the research undertaken in both phases of this project are presented in the next chapter.

5 KEY RESEARCH FINDINGS AND CONCLUSIONS

5.1 INTRODUCTION

This chapter summarises the research findings and discusses the impact of the research on the industrial sponsor and its implications for the wider construction industry. Recommendations and suggestions for future research are also given. Finally, the chapter critically evaluates the research and presents the overall conclusions.

5.2 REALISATION OF AIM AND OBJECTIVES

This project's aim was to facilitate the realisation of business benefits from the adoption of mobile information and communication technologies, both in a company and project environment. The project focused on documenting the application of mobile computing technologies to enhance key processes and the delivery and collection of information from mobile workers. The specific objectives of the project were:

1. to understand the information requirements of relevant personnel, particularly at points of activity remote from normal office systems;
2. to recognise the key communications between mobile workers, their company and the project team and look for ways to support these using existing and emerging mobile IT;
3. to establish the business case for the use of mobile technologies to facilitate relevant communications in construction; and
4. to analyse attitudes towards the use of IT in construction and discover any cultural or other barriers to its implementation.

Table 5.1 provides a summary of how this research has satisfied these objectives. These findings are then discussed in detail in Section 5.3.

Table 5.1 Summary of findings

Key

P Primary evidence

S Supporting evidence

Objective	Finding	Paper 1	Paper 2	Paper 3	Paper 4	MSc dissertation
1. To understand the information requirements of relevant personnel, particularly at points of activity remote from normal office systems.	The document types that site-based personnel would find most useful to have access to/record in the field (out of the office) were drawings, data collection forms, correspondence, progress information and specifications.	P				S
2. To recognise the key communications between mobile workers, their company and the project team and look for ways to support these using existing and emerging mobile IT.	The key processes most suited to the implementation of mobile IT, using currently available technologies, involve structured data collection e.g. health and safety inspections, maintenance inspections and progress monitoring.	S	S	P	S	S
2. To recognise the key communications between mobile workers, their company and the project team and look for ways to support these using existing and emerging mobile IT.	The technologies currently available to support these processes are PDAs, handheld computers, Tablet PCs and Mobile phones. Data transfer is possible through GPRS, WLAN and/or synchronisation. Auto-ID can also be combined with these technologies.	P			S	S
3. To establish the business case for the use of mobile technologies to facilitate relevant communications in construction.	ROI for a mobile solution is commonly achieved in less than 12 months. The benefits derive from improving efficiency of data capture, access to data, and data integrity. Many of the improvements demanded in construction can be facilitated by enabling point-of-activity workers to participate in the electronic flow of information.	S	P		S	S
4. To analyse attitudes towards the use of IT in construction and discover any cultural or other barriers to its implementation.	Contrary to a widely held belief in the construction industry, site-based staff are ready and willing to use mobile technologies to communicate with the wider team. The overall levels of access to I.T. are high with the majority of site leadership having direct (unshared) access to a computer at work, and access to the Internet.	P	S			S
4. To analyse attitudes towards the use of IT in construction and discover any cultural or other barriers to its implementation.	In order to achieve successful implementation it is important to: have a senior executive to champion the technology; early involvement of the users; undertake upfront process analysis; choose the most suitable user-interface, develop a solution with a short learning curve and provide sufficient training.	S	P			S

Using these results, the overarching aim has been achieved through the publication of the academic papers contained in this thesis and a series of case studies, articles and reports which have increased industry awareness of the potential for mobile technologies use in construction, highlighting the business benefits available and the steps to ensure a successful mobile project (see www.comitproject.org.uk).

5.3 SUMMARY OF FINDINGS

5.3.1 INFORMATION REQUIREMENTS

The survey found that site-based personnel are both recipients and producers of paper-based information. The paper-based tasks that they carry out in their normal work were numerous (85 different tasks were identified). These were grouped into different document types revealing the most commonly identified tasks as completing data collection forms (25%), dealing with correspondence (18%), viewing and reviewing drawings (13%) and reading and writing specifications (6%).

It was shown that the documentation to which site-based personnel would like to have access in the field is related to the paper-based tasks that they carry out as part of their normal work. This provides support for Tenah (1986) who found that information needs are inextricably linked to the management responsibilities of each member of the project team. The document types that site-based personnel would find most useful to have access to/record in the field (out of the office) were drawings (24%), data collection forms (12%), correspondence (8%), progress information (7%) and specifications (7%).

In the usability tests the participants were asked to view and annotate a drawing, search for information in a method statement, enter an event in a site diary and complete an inspection test sheet using four different hand-held computers. They were then asked which of these document types it would be most useful to have access to in the field; 'method statements and similar documents' were most useful, followed by 'drawings', then 'inspection test sheets and similar documents' and least useful was the 'diary'. However, they were least satisfied with using the devices for viewing and annotating drawings.

These results indicate that an alternative way of delivering drawing information in the field is required or devices/drawings need to be adapted to improve their delivery by electronic means. The author's experience shows that currently drawings are used in the field either in A3 or A2 paper format. In order to gain the benefits that electronic delivery can bring further research should be undertaken to obtain the most appropriate solution.

5.3.2 POTENTIAL APPLICATIONS

Construction industry personnel are required to undertake much of their work, during the construction and operation and maintenance phases, at the point-of-activity. For example, visual inspections for quality, progress and health and safety cannot realistically be carried out remotely. Therefore, it is not surprising that since the arrival of affordable mobile technologies many construction processes have been suggested as offering potential for improvement through using mobile IT (see Table 5.2). These can be categorised into communication, data capture and identification processes.

A subjective assessment, based on the industry experience of a group of construction professionals, resulted in the identification of the top ten processes perceived to offer the most potential for improvement through the use of mobile IT (shown in red in Table 5.2). It can be seen from this table that the majority of processes identified as having potential to benefit from mobile IT are structured data capture processes e.g. health and safety inspections, maintenance inspections and progress monitoring. It should also be noted that although those processes shown in black in Table 5.2 were not selected in the top ten these may offer potential improvements and their business case may be justified as outlined below in Section 5.3.3.

Table 5.2 Potential applications for mobile IT

Process	Classification	Identified in: Literature review	Identified in: Case studies	Identified in: Process mapping
Goods received notes	Data capture			Y
Drawing distribution and usage	Communication	Y	Y	Y
Task allocation	Communication	Y	Y	Y
Monitoring progress	Data capture	Y		Y*
Monitoring health and safety on site	Data capture	Y	Y	Y*
Quality inspections	Data capture	Y		Y
Site design problem resolution	Communication	Y		Y*
On-site accounting of operatives/visitors	Identification			Y
Maintenance inspections	Data capture	Y	Y	Y*
Site diaries	Data capture	Y		Y
Timesheets	Data capture	Y	Y	
Defect management	Data capture	Y	Y	
Correspondence	Communication	Y	Y	
Field observations	Data capture	Y	Y	
Plant and materials tracking	Identification	Y		
Site investigation	Data capture	Y		

*These four processes were chosen to be implemented on the demonstration projects.

The process mapping activity identified areas that could be improved through the use of mobile IT; these benefits are summarised in Section 5.3.3. Often several mobile technologies should be used to provide an end to end solution for a process (see Table 4.4). For example, a PDA can be used to collect and retrieve data; this can be aided using Auto-ID to identify objects or people. The collected data then needs to be transferred back to a database via WLAN, GPRS, 3G or synchronisation and then alerts and/or updates can be issued using SMS to mobile phones.

5.3.3 THE BUSINESS CASE

A business case provides the information necessary to make a rational decision about whether a project should proceed. It assesses the value of an investment in terms of its potential benefits and the costs involved. There are many generic benefits of mobile IT solutions which can be broadly categorised as:

- improving efficiency of data capture;
- improving access to data, reducing errors; and
- improving data integrity.

These benefits have been discussed in detail in Section 4.2.3.2, Paper 2 (Appendix 2) and Paper 4 (Appendix 4). Table 5.3 provides a summary of the benefits derived through implementing mobile IT applications to support the desired process improvements in construction.

Table 5.3 Mobile IT support for construction process improvement

Improvement target	Support provided by mobile IT solutions	Benefits
Reduction in construction time Reduction in capital cost	Provision of information to and from the point-of-activity provides cost and time reductions common to all of the applications outlined below.	Elimination of rewriting/retyping Reduction in travel time to retrieve information Reduction in travel time to view point-of-activity.
Reduction in defects	PDA and digital pen solutions for collecting snagging data. Mobile solutions deliver working drawings and data required to piling crews. GPS assisted machinery provides accuracies of a few millimetres.	Data is collected in a uniform format enabling trend identification e.g. underperforming sub-contractors. Better information enables a proactive approach to eliminating recurring defects. Defects are reduced due to access to more accurate and up to date information eliminating costly remedial work.
Reduction in accidents	PDA and SMS solutions used to conduct health and safety inspections and report near misses. Virtual exclusion zones created around hazardous areas e.g. a crane or a piling rig. Alerts can be sent directly to personnel entering the area. Remote controlled GPS guided machinery to work in hazardous areas e.g. in a volcanic area.	Corrective actions are completed more swiftly preventing potential accidents. Persistent non-compliances can be identified enabling a proactive approach to eliminating reoccurring hazards. Only qualified personnel can enter hazardous zones eliminating potential accidents. People can be removed completely from hazardous areas.
Increase in predictability	Mobile solutions for timesheet, plant utilisation, materials management and progress reporting. Accurate real-time progress and cost information collected as the project progresses.	Planned progress and the budget can be compared in real-time with the actual progress/costs. This information can be used to inform later project stages and/or future projects.

Improvement target	Support provided by mobile IT solutions	Benefits
Reduction in waste	Materials delivery monitored through the use of PDAs for goods received notes and proof of delivery. Barcoding and RFID tag technologies to track equipment and materials. GPS and GIS monitoring of suppliers enabling just-in time delivery and hence a reduction in temporary storage facilities. RFID tagging of components identifying their make-up.	Accurate record of materials delivered to site. Faster location of materials and equipment eliminating duplicate orders. Certainty that the correct materials are used eliminating damaged materials. Return of unused materials and reduction in lost or stolen items. Reduction in damaged items within temporary storage. Increased recycling of components during refurbishment or demolition.
Increase in productivity	Task automation enables the delivery of required information, production of reports, alerts and data collation. Mobile solutions enable communication from the point-of-activity to resolve unforeseen problems. Mobile solutions assist the Last Planner process eliminating the paperwork required to operate this lean construction initiative.	Reduction in the number of administration staff required. Reduction in downtime waiting for personnel to get to site. Elimination of misunderstanding of the problem and hence the time spent producing an unsuitable solution. Reduction in the administration time required to operate the last planner process whilst enhancing the collaboration and face to face aspects.
Reduction in O&M costs	PDA solutions for delivering work orders and undertaking maintenance inspections. GPS to monitor the location of staff and vehicles. As-built information collected as the project is constructed. This can be embedded in the structure through the use of RFID tags. Embedded sensors alerting owners when maintenance is required.	Improved inspection data enables proactive scheduling of maintenance. Reduction in administration support required. Real-time progress reporting to clients. All information required available at the point-of-activity. Improved logistics reduce mileage and hence fuel and fleet maintenance costs. Routine maintenance automatically scheduled. Prevention of component failure and hence avoidance of replacement costs.

The case studies conducted as part of this research showed that all of the applications achieved process improvement; however, the process improvements achieved in the unsuccessful cases were not sufficient to offset the costs incurred. This highlights the need to formulate a business case prior to developing a solution to fully understand the quantitative costs and benefits that should be incorporated.

It should also be borne in mind when developing the business case for an application that justifying the business case for one process can be enhanced by choosing a process that utilises information common to other processes. The mapping approach that was followed as part of this research enabled the identification of common deliverables and personnel across the ten processes (e.g. the project plan is utilised in the processes for monitoring progress, task allocation, goods received notes, quality inspections and site diaries). Once the first process has been "mobilised" some of the electronic data required to mobilise a subsequent process is already provided. Additionally, the equipment required is already available, the users may be the same and hence the barrier to acceptance of a new solution is lowered, and also the training required is reduced.

This research has shown through the case studies that return on investment for a mobile solution is commonly achieved in less than twelve months. To aid the production of future business cases it also provides guidance on which processes should be "mobilised" in which order, although the benefits achievable should also be taken into account.

Figure 5.1, derived from the process mapping activity, illustrates how closely related the information requirements of each process are. The lengths of the adjoining lines are inversely proportional to the number of deliverables (inputs and outputs) that each process has in common. For example, if the Monitoring Progress process was mobilised then several of the outputs from this process are used in other processes, hence part of the work to mobilise them will have already been undertaken.

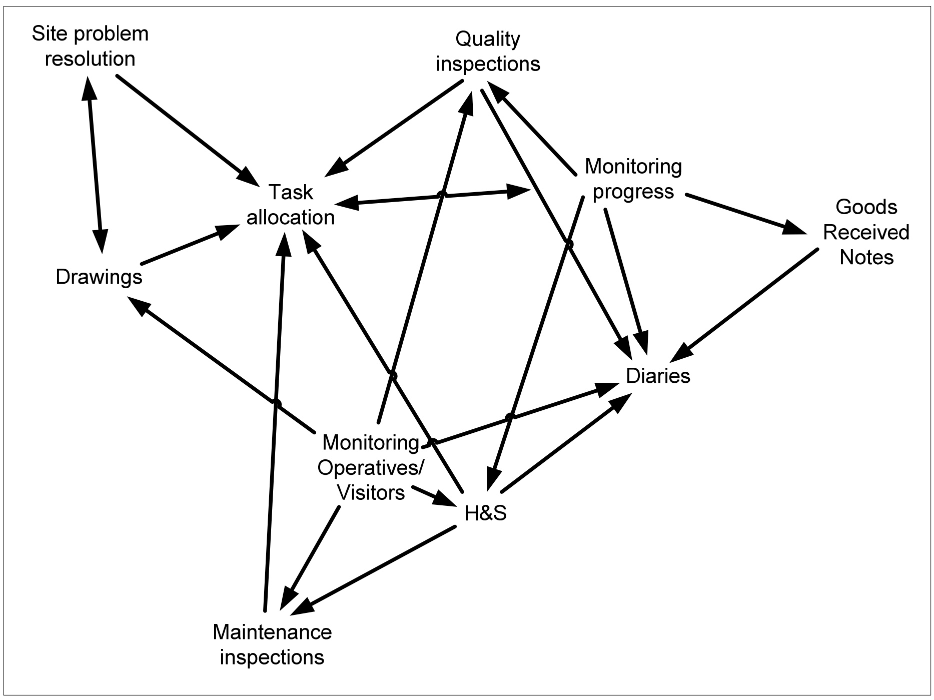

Figure 5.1 Process linkages illustrating common information for each process

5.3.4 ACHIEVING SUCCESSFUL IMPLEMENTATION

Ward (2004) cited three reasons given for the slow uptake of “at source” data capture:

- perceived lack of suitable devices;
- perceived lack of computer literacy; and
- perceived high cost.

Figure 5.2 illustrates how this research project has addressed each of these barriers to reach a point where the COMIT community and the wider construction industry have enough information to see that these barriers can be overcome. Following the implementation guidance drawn from this study, successful implementation and hence a rapid return on investment can be achieved by:

- having ongoing involvement of a senior executive to champion the use of the technology;
- having early involvement of the users to fully understand their needs and develop a sense of ownership of the solution;
- undertaking upfront process analysis to understand the data collection requirements;
- choosing the most suitable user-interface, and hence device, for the users’ data collection and retrieval activities; and
- developing a solution with a short learning curve, and
- provide sufficient training and ongoing support.

Each of the barriers is discussed in more detail in the following sections.

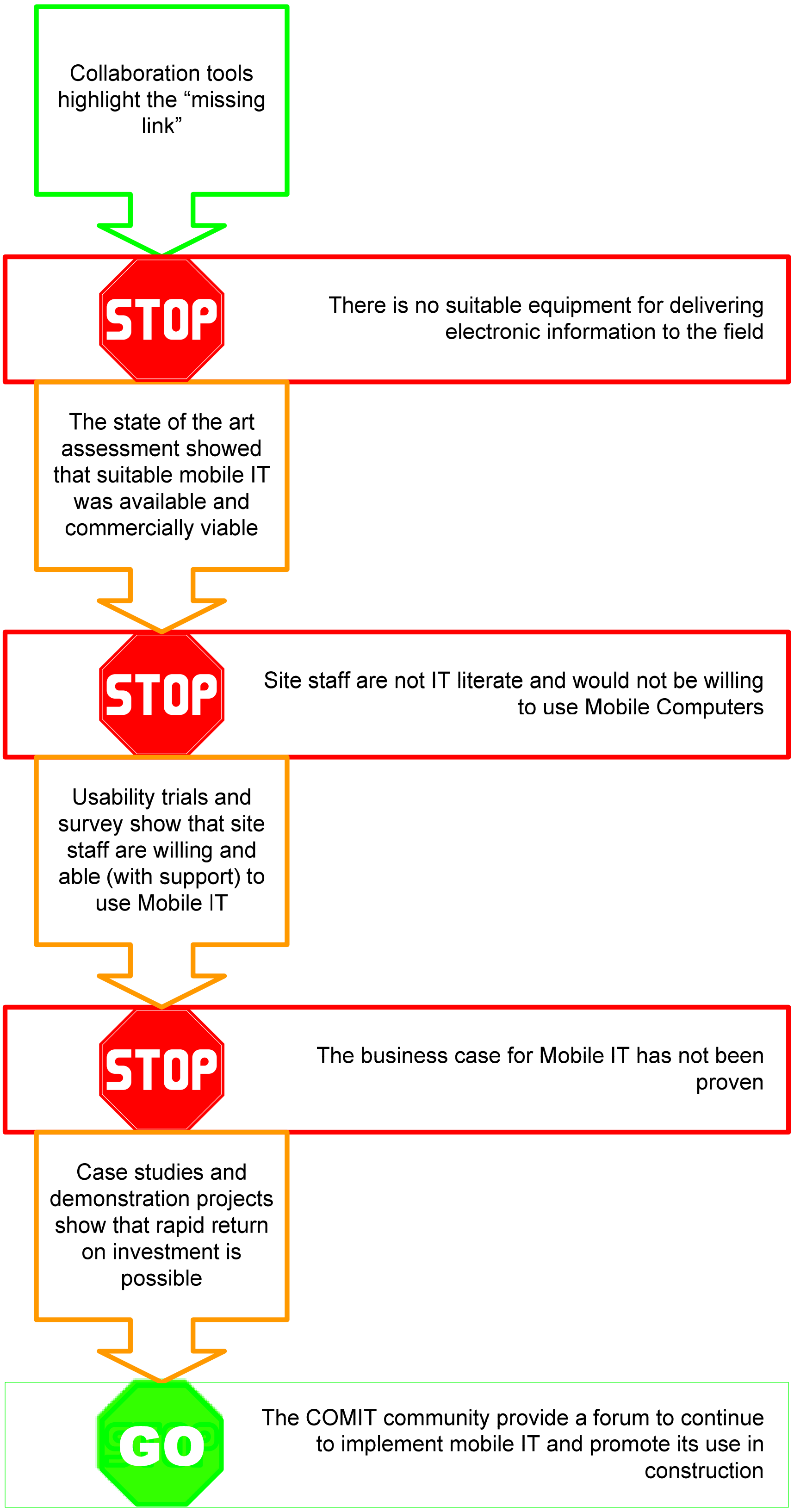

Figure 5.2 Research route to overcome the perceived barriers to mobile IT use in construction

5.3.4.1 Perceived lack of suitable devices

Half (50%) of the survey respondents who did not think that hand-held computers could be used on site thought that they would not stand up to the harsh site environment. Even by exposing site-based personnel to examples of the rugged devices in the usability tests many of the participants still recommended that the devices should be more rugged and that the screen should have some form of cover. The device breaking was a particular concern as this could lead to lost data and therefore lost productivity.

However, the case studies illustrated that the hardware chosen was often not fully rugged. Only one application adopted a fully rugged device with three applications taking a semi-rugged approach (i.e. a device with a rugged case and the remaining applications using non-rugged devices e.g. the digital pen and mobile phone). One reason for this is given in the Tablet PC case study where it was decided to use a semi rugged instead of fully rugged device as the fully rugged devices were not considered cost effective (being four times as expensive). Also, due to the fast pace of hardware improvement, it was felt that there is more flexibility in using a cheaper device and replacing it more often.

To overcome the issue of losing information should the device be damaged several of the solutions stored their data on a memory card that could simply be removed from the broken device and reused in a new device. Another method to avoid data loss was to store minimal data on the device itself and transfer the data live via GPRS or WLAN back to a central database.

5.3.4.2 Perceived lack of computer literacy

As explained in this thesis, IT literacy is a subjective term. The survey showed that site-based personnel often have high levels of access to and usage of IT. IT knowledge also appears to be reasonable with respondents having used an average of six of the main computer applications. However, the IT literacy measure used in this survey illustrated that 'foremen/works managers' and the age group '55+' have the lowest level of access, usage and knowledge. It should be noted that these results should be treated with caution since these groups were underrepresented in the sample.

Over two-thirds (69%) of the respondents had received no formal IT training; they either taught themselves or learnt through colleagues. Therefore although 68% of contractor firms say they have an IT component within their management training programmes (Building Centre Trust, 1999), this does not appear to be provided to the majority of site-based personnel. Over three-quarters (78%) of the respondents thought that further IT training would be beneficial.

However, previous experience of IT and use of hand-held computers appeared to have no effect on the uptake and satisfaction in using hand-held computers as shown by the usability trials. Fifteen out of the seventeen (88%) participants confirmed that they would be happy to use a handheld device for their work. Typical comments were 'superb', 'very powerful' and 'definitely see an advantage'.

5.3.4.3 Perceived high cost

Participants in the usability tests thought that the costs involved in purchasing a device would outweigh the benefits gained. At approximately £1,200 for a rugged device many participants thought that management would have to be convinced that purchasing these devices was worthwhile. However, they suggested that, potentially, these devices could replace the provision of desktop computers to some operatives. This would provide direct savings both in terms of the equipment and also the security provisions that are made. Section 5.3.3 details the business case for applying mobile IT to suitable processes and concludes that return on investment is possible within twelve months.

5.4 CONTRIBUTION TO KNOWLEDGE AND PRACTICE

The value of this research and its originality can be demonstrated both in the mobile IT and construction research areas.

5.4.1.1 Contribution to mobile IT research

The study of human computer interaction for mobile devices is a relatively young research field in which commercially successful devices have been available for less than a decade and leading conferences have only a few years of history. Recent research has shown that there has been a distinct bias towards building systems and evaluating them only in laboratory settings, and a significant lack of research conducted about mobile IT use in real-world contexts using case studies and action research (Kjeldskov & Graham, 2003). Kjeldskov and Graham (2003) highlighted the need to expand the methods used within the field of mobile HCI research:

- surveys could be used to collect large amounts of data from, for example, actual end-users of a system. This approach offers a good opportunity to study the use of systems in the hands of a large segment of the population, enabling wider reaching generalizations;
- case studies within mobile HCI could increase learning from existing implemented systems within real-world contexts. This would enable the close scrutiny of pre-defined phenomena in fixed contexts, which could then be used to enrich the collective knowledge in the discipline and to enable key issues to be described and understood; and
- the limited use of action research points to both the lack of a well-established body of theoretical research within the discipline and the unwillingness to implement mobile systems which are uncertain to succeed and take a long time to evaluate and implement. This is perhaps not surprising, given the current cost of such technology and the associated implementation overhead. Nonetheless, this is, again, an opportunity to develop knowledge in the discipline through practice and evaluation.

This research has made use of each of these methods and provides useful case study material and results from real-life applications of mobile IT. In contrast to laboratory evaluations, true mobility of the end-users has been examined in the context of their work environment. In this case it was a construction site in which the end-user has to contend with a dirty, sometimes wet, environment containing moving vehicles and other hazards, working in changeable weather and needing to view the screen in both bright daylight and sometimes darkness.

In addition, the abilities and information needs of the actual end-users themselves have been taken into account; this in turn provides useful information for developers of future mobile solutions for the construction industry.

5.4.1.2 Contribution to construction research

Since the late 1980's, both the academic and industrial sectors have been investigating the use of mobile IT for developing applications used in field data collection within the construction industry. Researchers have investigated the application of mobile IT to many processes including monitoring piling activities (Ward *et al.*, 2003), site diaries (Scott, 1990) and quality inspections (Cox & Issa, 1996). However, much of this research has focussed on identifying future scenarios, prototype development, experimental or one-off pilots and only involved construction companies to a limited extent. This echoes the findings of Kjeldskov and Graham (2003) for general mobile IT research (see Section 5.4.1.1 above).

This study has deliberately focussed on gaining real-life industry feedback on the use of mobile IT in construction through usability trials, case studies and demonstration projects and the involvement of industry practitioners throughout. It has taken the theoretical idea that mobile IT use in the construction industry would be beneficial a step further and identified and overcome the barriers to mainstream adoption. Through widespread dissemination of the real-life examples of mobile IT already in use it is expected that this will encourage further adoption.

5.5 IMPLICATIONS FOR THE SPONSOR

5.5.1 SATISFYING MOBILE INFORMATION NEEDS IN ARUP

The research conducted for this project initially incorporated understanding the mobile information needs of Arup users. However, it quickly became apparent that the majority of Arup employees are either fixed or nomadic workers moving from LAN to LAN and therefore outside the scope of this research (see Section 1.5.2). The minority of employees that had truly mobile information needs were the executives and their primary requirement was for email and PIM programs that provide information such as appointments, contacts, notes, lists and memos. The BlackBerry was implemented to meet these needs and as part of this research a case study was undertaken on its use within Arup (Bowden, 2004a). The BlackBerry service has enabled Arup employees to make productive use of what was traditionally “downtime” e.g. travelling to and from meetings. It has also enabled staff to stay in contact more easily when they are visiting other offices or out on site. Staff feel more in control of their work and no longer return to the office to an overflowing mailbox. Initially there was some concern with regard to the cost of the service and whether it offered value for money. The three areas in which the BlackBerry provided added value are:

- immediacy and improved responsiveness;
- increased productivity; and
- direct savings in the form of alternate communications and mobile device expenses.

The total cost of ownership of the BlackBerry was calculated as £520 (based on 114 users). The return on this investment depends on the value of the employee’s time and how much time they spend out of the office. The payback period for a typical Arup user is between 30 and 60 days. However, there is still some discussion about the value of the BlackBerry in certain groups due to the fact that, although staff are now making better use of downtime, they will not be charging more to their clients and hence there will be no net increase in fees. This argument will only be resolved when it can be shown that staff can now take on more project work due to being able to make better use of their time.

5.5.2 INCREASED COMMUNICATION WITH THE SITE-BASED PROJECT TEAM

As indicated above, Arup's engineering consultants, will not currently be the primary end-users of mobile IT. However, they will benefit from being indirect users of the information collected at the point-of-activity (see Paper 2: Table 2, Appendix 2). This closing of the information loop could prove very valuable in breaking down the barriers between consultants and contractors (Latham, 1994). Potential improvements are possible in the following areas:

- Designing for safety: the collection of data relating to hazards on site enabling the identification of trends could provide insight into those hazards which should be designed out;
- Designing for buildability: increased communication with the contractors who actually have to build the structure could enable the development of more practical designs;
- Understanding site information needs: increased communication with the end-users of the design information could help to ensure information is delivered in the correct format eliminating the need to reformat and the additional time and costs and potential transcribing errors;
- Resolution of unexpected problems: contractors will be able to communicate more easily with the remote designers and provide a true picture of the problem without needing the designer to travel to site, thus enabling the swift resolution of unexpected problems;
- Closer working relationships: The "Them and Us" mentality in the industry could be alleviated through increased communication. This will undoubtedly have a positive effect on the project.

5.5.3 DEVELOPMENT OF A NEW BUSINESS STREAM

The knowledge and experience gained through this research is now enabling Arup to bid for work in the area of Construction ICT consultancy; providing a new stream of business. This will not only form a new source of income, but will also be used to enhance the projects that Arup employees work on enabling them to benefit from enhanced communications and hence working practices.

5.6 IMPLICATIONS FOR WIDER INDUSTRY

This research project has illustrated that many of the perceived barriers to the uptake of mobile technology solutions in construction are either non-existent or can be easily overcome. The outputs of this research will enable contractors to pursue the development and implementation of mobile solutions and hence benefit from significant improvements in reducing construction time and cost, defects, accidents, waste and operation and maintenance costs whilst improving predictability and productivity. The implications for designers are outlined in Section 5.5.2 above.

With any introduction of new technologies into the construction industry, the technology itself is only part of the solution; the effects on the people and processes involved should also be considered. Paper 4 (Appendix 4) highlights three areas which should be considered as the uptake of mobile technology solutions increases: the potential for new islands of automation; the effects on human resources, and the potential impact on knowledge management initiatives.

New islands of automation should be avoided by ensuring that any adopted mobile solution can link into a variety of core IT systems e.g. collaboration tools, project models and knowledge management systems. This will enable teams to gain the maximum benefit by aiding the seamless transmission of information and processes between life cycle phases, providing better process understanding, reusing past project knowledge in new developments, and achieving process improvement.

The successful implementation of new technologies and the resulting new ways of working will require very different skills of future field leadership workers. For example, on site, construction managers and foremen will need to make more use of information and communications technology to schedule and report on work, and will require organisational and interpersonal skills to enable collaborative working amongst multi-disciplinary teams. The attitude of “that’s the way we’ve always done it” will no longer be acceptable and an openness and input to new ways of working will be expected.

The current skills shortages could be addressed in two ways. Firstly, mobile technologies which enable productivity improvements could reduce the resources required, and secondly, as the construction industry becomes a safer, more efficient and innovative place to work in it should begin to attract more people with the right skills.

The importance of knowledge management has been recognized by the construction industry and is seen as a mechanism not only to avoid reinventing the wheel but also to encourage innovation and overall improvement. There is a greater recognition that workers at all levels of the organisation are a significant source of creative thinking; however, the live capture and reuse of construction project knowledge has remained a major challenge that has not yet been adequately addressed (Udeaja *et al.*, 2004). Mobile technologies could provide the link to workers at their point-of-activity so that lessons learnt as the project progresses are captured immediately. This not only provides information to improve future projects, but the real-time knowledge can also be incorporated in future phases of the current project.

5.7 CRITICAL EVALUATION OF THE RESEARCH

The quality of research findings is dependent on the choice of research methodology, the data gathered, and the statistical tools used (Walker, 1997a). The reliability of the results can be influenced by the validity of the research instrument (e.g. the questionnaire), the validity of the data gathered, the appropriate use of statistics and the validity of the conclusions drawn.

The following constraints have been recognised:

- Using a questionnaire as the research instrument allows people to decide whether or not to reply. The likelihood, repeatedly confirmed in practice, is that people who do not return the questionnaires differ from those that do (Moser & Kalton, 1971). Therefore the results may not be wholly representative of the target population. If this research were undertaken again the author would recommend using interviews as the research instrument to ensure that a balanced representation of views is obtained.
- The Usability Tests were not carried out in a real-life situation. This may have had the effect that the participants were inclined to say what they expect the researcher wants to hear. They were also not exposed to the potential difficulties which long-term usage of the devices would bring to light. The tests were carried out with personnel from one project only, which provided a relatively small sample of 17 people. Therefore, caution must be exercised in extrapolating these results and they should only be considered indicative.
- The candidates for potential case studies were found through conducting an extensive literature review and industry consultation. However, it is human nature that primarily only successful examples are publicised and this limited the extent to which unsuccessful examples could be explored. It would be very useful to conduct case studies for further unsuccessful examples of the processes that have been examined in order to verify whether the contributory factors could be predicted from the results of this research.
- The selection of the processes that could be improved through the introduction of mobile IT was subjective to a degree. However, inherently there are many objective and subjective factors that will influence the successful implementation of mobile IT and it was felt that the industry representatives were best able to judge this. The subjective scores given in the narratives by the author were subsequently verified by the construction industry representatives and considered satisfactory.

5.8 RECOMMENDATIONS AND FURTHER WORK

This section sets out areas of research highlighted during the course of this research project that could not be addressed within the timeframe. Table 5.4 brings these together as a framework for future research. brings these together as a framework for future research.

Table 5.4 Framework for future research

Key

- **P** Primary source
- **S** Supporting source

Topic	Need for further research	Foundation: Paper 1	Paper 2	Paper 3	Paper 4	EngD Thesis
Facilitating end-user acceptance of Mobile IT in the construction industry	User acceptance is often the pivotal factor that determines the success or failure of an IS project and unless this is achieved none of the benefits will be achieved. In this research only a relatively small sample (17) participated in the usability trials which provide an indication of their views only and cannot be generalised to the population.	Section 7 (S)	Section 5.3 (S)		Table 3 (S)	Section 5.8.1 (P)
Optimising software development for the construction industry	During the demonstration projects, several of the software providers commented that they would like to know what factors influence the successful development of a solution that meets the client's needs. An ideal software development participation framework could be developed taking into account the specific construction industry context.		Section 5.4 and 6 (S)			Section 5.3.4 and 5.8.2 (P)
Addressing unsatisfied information requirements	The delivery and annotation of drawings has been identified as a mobile information requirement at several stages in this research project. Current mobile IT does not satisfactorily satisfy this requirement. Further research should be undertaken to understand what drawing data is actually required on site and how this can best be delivered.	Section 5 (S)		Section 6.1 (S)		Section 5.8.3 (P)
Understanding the knowledge management and workforce impacts of enabling the mobile workforce to participate in information workflows	Mobile IT could enable the live capture and reuse of construction project knowledge providing real-time information to improve both current and future projects. Further research is required to understand the implications of capturing this knowledge and the new skills required by the workforce.		Section 5.2 and 5.3 (S)		Section 6.2 and 6.3 (P)	Section 5.5.2 and 5.6 (S)
Integrating mobile solutions with mainstream construction software applications	Ad-hoc development of isolated, function driven, mobile solutions for the construction industry risks the creation of new islands of automation. Research should be undertaken to understand how processes supported by Mobile IT fit into mainstream data stores, ensuring interoperability and hence gaining maximum benefit.	Section 5 and 10 (S)		Section 8 (S)	Section 6.1 and Table 1 (P)	Section 5.5.2 (S)
Addressing further barriers to mainstream adoption	As the uptake of mobile solutions in construction becomes more common, more quantitative research, which could be generalised to the construction industry as a whole, can be undertaken to understand what the common barriers are and how these can be overcome.	Section 8 (S)	Section 5.4 (S)		Tables 2 and 3 Section 6 and 7 (P)	Section 5.3.4 (S)

Further detail and suggested initial references are given below for first three topics that have been highlighted:

- the acceptance and usability of new technologies;
- the software development phase; and
- addressing unsatisfied information requirements.

5.8.1 TECHNOLOGY ACCEPTANCE

As this study has concluded, the benefits of mobile IT systems should be demonstrated at organisational, project and user level. User acceptance is often the pivotal factor that determines the success or failure of an IS project (Venkatesh & Davis, 2000) and unless this is achieved none of the benefits will be achieved. Since user acceptance is such a vital constituent for success there have been many attempts to provide a framework for understanding why users accept or reject IT systems including:

- TAM – the technology acceptance model (Davis, 1993)
- TPB – the theory of planned behaviour (Ajzen, 1991)
- TAM2 – a revised technology acceptance model which incorporates TPB (Venkatesh & Davis, 2000)

The technology acceptance model proposed that the two fundamental determinants influencing future usage levels are:

- Perceived usefulness - "the degree to which a person believes that using a particular system would enhance his or her job performance";
- Perceived ease of use - "the degree to which a person believes that using a particular system would be free of effort".

This was expanded to include further factors as shown in Figure 5.3 below.

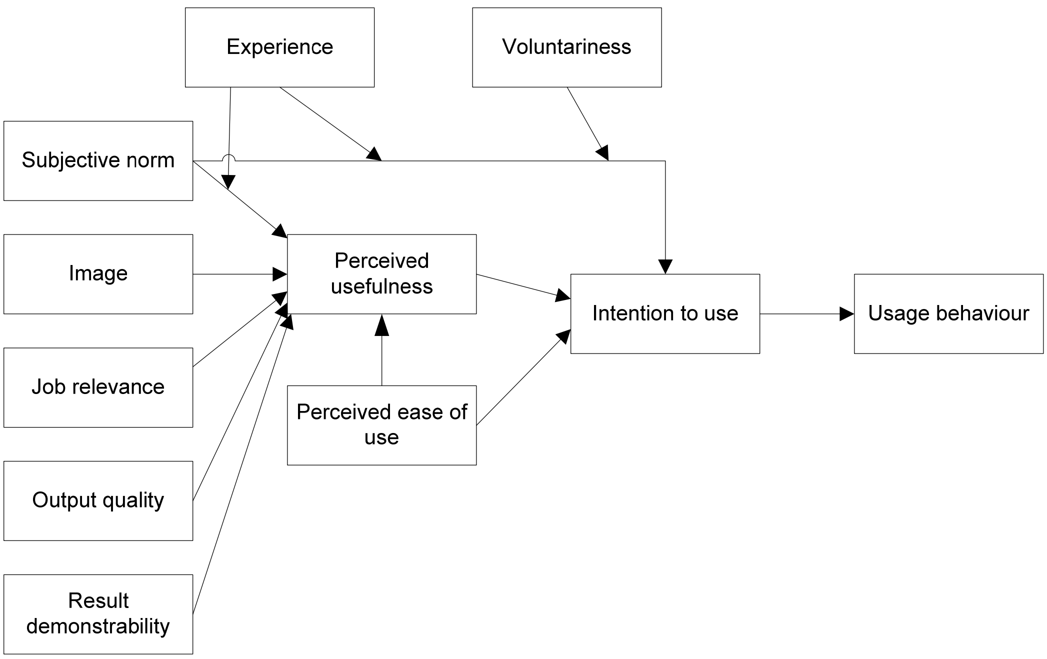

Figure 5.3 TAM2 - revised technology acceptance model (Venkatesh & Davis, 2000)

Davis (1993) makes the distinction between subjective and objective measures of usefulness and ease of use and that these are often in disagreement. HCI usability studies, such as the one undertaken as part of this research, focus on objective measures of ease of use and, although this is clearly relevant to user performance, subjective ease of use is more relevant to the users' decision whether or not to use the system in question.

Although a few studies have already been undertaken on acceptability of mobile IT applications in the consumer environment (e.g. Hung & Chang, 2005, Lu *et al.*, 2003), it is proposed that further research should be carried out to understand how these frameworks could be used in the context of this research to facilitate the design and acceptance of mobile IT applications in the construction industry.

5.8.2 SOFTWARE DEVELOPMENT PHASE

During the software development phase of the demonstration projects, several of the software providers commented that they would like to know what factors influence the successful development of a solution that meets the client's needs. There have been several studies into this area showing the importance of early user input (e.g. Nandhakumar & Jones, 1997) and teamwork during the IS development phase (e.g. White, 1984). Yang (2004) brought these fields together and looked in greater depth at the relationship between team structure, user involvement and the software development team performance using a social network approach.

This research could point to an ideal software development participation framework. However, as recognised by Dyson and Er (2004), there are a number of practical considerations which make it difficult to gain the participation of construction industry workers in the design of a new technology:

- construction sites are extremely busy places. There is an issue with technology designers wasting workers' time, and a reluctance by workers to give time to the design of a technology for which they have difficulty envisioning any benefits in the early stage;
- given the resistance to new technology, there is a credibility issue, with designers feeling reluctant to risk future access to building industry contacts and site visits by losing credibility if they present very low fidelity prototypes to users, who might see these as absurd and become disinclined to participate; and
- safety regulations place impediments in the way of outsiders gaining access to building sites to test prototypes on workers and therefore it is necessary to employ any site visits obtained judiciously.

Further research is required through case studies and demonstration projects in this area to determine the optimum level of user involvement taking into consideration their limited availability. Substitutes for user involvement should also be explored.

5.8.3 UNSATISFIED INFORMATION REQUIREMENTS

The delivery and annotation of drawings has been identified as a mobile information requirement at several stages in this research project: the survey, the usability tests and the process mapping. Although it was selected as one of the ten processes having potential for improvement through the use of mobile IT, it was felt that although drawing control could be aided through bar-coding the paper copies, current mobile technologies were not suitable for the delivery of electronic drawings to the point-of-activity. Although there are several packages available for use on a PDA (e.g. PocketCAD) the participants in the usability tests felt that the form factor of PDA is not suitable for viewing drawings which are designed to be read at a minimum of A3 size.

There are rugged Tablet PCs available that provide larger screens to view drawings effectively; however, providing these to everyone on site that needs to look at the latest drawings would be subject to financial constraints.

One potential solution would require a step-change in the way the industry presents its design information. As construction moves towards a more data-centric approach through initiatives such as the Building Information Model, it may be possible to deliver the data required to site rather than the entire drawing (e.g. the depth required for the drainage pipe). The form factor of the currently available mobile devices would no longer be an issue.

Another potential solution could be e-Paper linked to a WLAN to access the latest drawings from a collaboration tool. There are various compression technologies available that could be utilised to reduce the drawing file-size to reduce the transfer rate. e-Paper is only just now moving from theory into the prototype application phase but should be explored when it becomes commercially viable. E-Paper will be available in any size, overcoming the form factor issue. Additionally, its key benefits include the viewing characteristics of paper, (high contrast, wide viewing angle, and visibility in bright daylight) and low power consumption since the device only requires power to change the image. This makes it a very attractive potential solution for drawing delivery to site.

5.9 SUMMARY AND CONCLUSIONS

There are many different mobile devices and software solutions to choose from to extend IT tools to site-based personnel. Contrary to common perception, site-based personnel appear ready and willing to use these devices to aid them in their work and to communicate with the wider team.

It has been shown that the majority of information requirements of site based personnel can be satisfied with currently available technologies, with the exception of drawings. The key processes which are most suited to the implementation of mobile IT involve structured data collection (e.g. health and safety inspections, maintenance inspections and progress monitoring).

Many of the improvements demanded in construction can be facilitated by enabling point-of-activity workers to participate in the electronic flow of information. The benefits of deploying a mobile solution derive from improving efficiency of data capture, access to data, and data integrity. These benefits result in return on investment commonly being achieved in less than 12 months. In order to achieve a successful implementation it is important to: have a senior executive to champion the technology;

ensure early involvement of the users; undertake upfront process analysis; choose the most suitable user-interface, develop a solution with a short learning curve, and provide sufficient training.

The adoption of mobile IT within the construction industry has been cited by Brandon (2005) as one of the areas of emerging practice that may contribute to reaching the ‘tipping point’ for an accelerated penetration of information technologies into the construction industry.

The ‘tipping point’ was identified by Gladwell (2002) as a phenomenon whereby an activity or a technology suddenly emulates the kind of behaviour that is similar to an epidemic in medical terms. For example, there was a tipping point when contractors of all sizes suddenly found the benefit of using the mobile phone to communicate in a difficult, distant and often dirty and noisy environment; construction was one of the first industries to widely adopt mobile telephony.

Brandon (2005) identifies six trends which could bring construction to the tipping point:

- Convergence – multi-media communications available through a single interface;
- Connectivity – anytime, anyplace, anywhere access to information;
- Culture – the IT educated generation are now entering the workplace;
- Creativity – flexible and adaptive IT provide support for new ways of thinking;
- Content improvement – content provided through IT is becoming indispensable;
- Collaborative working – dispersed teams are required to work on major projects.

Mobile IT has a part to play in each of these areas. It makes use of *convergence* enabling the provision of one tool to support multiple activities; it provides *connectivity* enabling *collaborative working* with geographically dispersed teams; the rapid adoption of mobile telephony in the industry provides a *culture* ready to adopt new tools through a familiar medium; it provides a medium for the collection of real-time information from the construction site hence *improving* the information *content* for the project team and this in turn will provide a new forum for *creativity* through improved information provision and the inclusion and communication with a wider team.

This research is expected to contribute to an increase in the uptake of mobile IT within the construction industry and hence facilitate reaching the ‘tipping point’ for an accelerated penetration of information technologies into the construction industry. Although mobile IT is not the only solution to the problems highlighted by the construction change initiatives, it does offer the potential of significant improvements in reducing construction time and cost, defects, accidents, waste and operation and maintenance costs whilst improving predictability and productivity. The construction industry needs to take measures to realise these benefits.

In summary the construction industry needs to:

- recognise that mobile IT can facilitate many of the improvements demanded for in the construction industry;
- confirm those areas where mobile IT can best serve their needs in the most cost-effective way;
- work more proactively with mobile solution providers to get the solutions that best fit the industry;
- evaluate and plan for pilot projects using readily available mobile IT solutions; and
- encourage point-of-activity workers to utilise their increasing awareness of IT.

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APPENDIX 1: PAPER 1

FULL REFERENCE

Bowden, S. and Thorpe, A. (2002). Mobile communications for on-site collaboration, *Proceedings of ICE, Civil Engineering*, 150 (November 2002), paper 12989, pp 38-44.

ABSTRACT

The construction industry's drive towards using information and communications technology to enhance collaborative working seems to have left site staff behind. This paper examines the information needs of site staff and shows there are several technology solutions currently available to support them. Based on a recent site trial, it also shows that, contrary to general perceptions, site staff are more than ready to adopt modern technology and should be included in all future strategies for collaboration systems.

1 INTRODUCTION

Currently there is much discussion about web based collaboration systems solving the industries' fragmentation problems. However, these systems are not yet in common use in the field e.g. by foremen and site engineers. The flow of electronic information comes to an abrupt halt when it reaches the construction site, only reaching selected personnel in the site office, and thus many of the efficiency and knowledge-based benefits of collaboration tools are lost. The extension of these tools to include site information needs will be an essential factor in eliminating these problems.

The information difficulties faced by site-based construction personnel have been described and documented in several studies over the last decade (Murray and Thorpe, 1996, Tenah, 1996). In its broadest sense information can be defined as the data and messages that are transmitted between people within a communications network (Mead, 2001). The ability to quickly convert data into information, while at the same time reducing the drudgery associated with many of the administrative tasks, improves both staff efficiency and work interest (Flowers, 1996).

It has been suggested that the cost of construction can be reduced by 25% through the efficient transfer of information (Baldwin et al, 1996, Davidson and Moshini, 1990). Many people have argued that construction products are one-off with each project being unique – however the same procedures and processes are adopted time and again (McConalogue, 1999). By enhancing information flow between the different site processes and teams, it is easier to monitor, control and assess the project progress and hence integrate the on-site process (Moniem, 2000). If information retrieval can be enhanced there are significant savings to be made. For example, BP Exploration (BPX) estimated that reducing the time needed to locate and acquire information would increase efficiency and result in annual savings of between $10 and $20 million (Cross et al, 1997).

2. UNDERSTANDING THE INFORMATION NEEDS OF SITE STAFF

There have been many attempts to categorise/identify construction information. Researchers have filtered site information to a greater or lesser extent. From a high level division into Technical, Commercial, Management and Control (BT, 1995) to a more detailed level where different types of documentation are classified e.g. Technical queries, Dayworks, Requisitions, Method Statements etc.(Murray and Thorpe, 1996). Tenah (1996) conducted his research from a slightly different angle, looking at the information needs of specific construction personnel. His study found a wide array of functions within construction organisations, and that information needs are inextricably linked to the management responsibilities of each member of the project team. Table 1 shows an example of the foreman's functions and information needs.

Table 1: A site foreman's functions and information needs (Tenah, 1996)

Primary Functions
Organises and coordinates employee engaged in a specific craft or function on a construction project.
Reads and interprets drawings, blueprints, and specifications.
Allocates, assigns, and inspects work.
Administers union agreements and safety enforcement; hires and trains employees.
Primary Information Needs
Blueprints, specifications, and other contract documents.
Local union activities, safety regulations and laws, labour agreements, quality control, and testing regulations.
Shop drawing and sample control, procurement status, bar chart by system or area, production schedules, and field performance reports.

The data on Figure 1 (Newton, 1998) indicates that 65% of contractor-rework is attributed to insufficient, inappropriate or conflicting information. Site issues need to be resolved quickly and efficiently to avoid cost overruns and this often requires collaboration between on and off-site personnel (Miah et al, 1998). However, most site information is currently stored on paper, which is difficult to access and requires large storage space. A computerised information system can store vast amounts of data efficiently, and information can be located and viewed quickly through computerised searching and display (Liu, 1995).

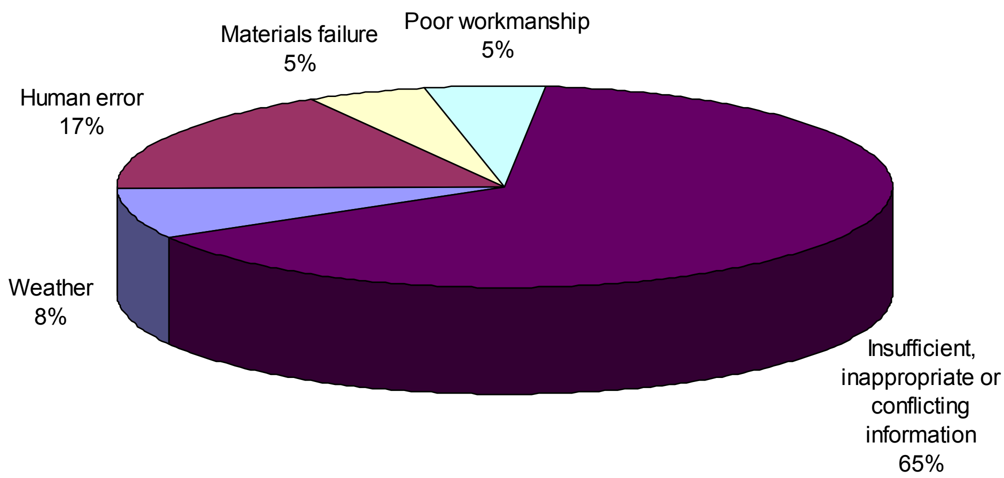

Figure 1: Contributory factors to contractor rework

However, we should not be aiming for a paper-less office/site, merely a less-paper office/site utilising information technology when and where it brings demonstrable benefits. The evidence is conclusive in that office automation has failed to yield the forecast utopia of the 'paperless office'. In fact, almost the exact opposite has happened: desks are now littered with computer printouts. People are comfortable with the “feel” of paper (Barrett, 1989). Further research into the current production rates of paper-based, electronically created information would be of value.

Construction project managers typically spend 70% of their time dealing (generating, managing, sending, collecting and analysis) with data (Fisher and Yin, 1992).

Tenah (1996) concluded that personnel who have good access to timely accurate information will

- reduce or maintain project durations
- make better use of resources
- increase labour and equipment productivity
- decrease cost.

In order to determine where information technology can be used in the delivery and capture of information on site to enhance collaboration with the project team the current site information needs and flows must be understood.

3 BENEFITS OF ELECTRONIC DATA IN CONSTRUCTION

Due to its very nature the construction industry requires its personnel to be mobile in order to complete the realisation of the project. To carry out their job function communication with others is essential and quality, quantity and timing of information can either hinder or facilitate successful results (De la Garza and Howitt, 1998).

The benefits of implementing electronic data capture systems in construction have been well documented (McCullough, 1993, McCullough, 1997, Baldwin et al, 1994, Songer and Rojas, 1996, Escheverry, 1996, Fayek et al, 1998, Navarette, 1999, Ward, 2001).

The benefits can be broadly categorised as follows

- improving efficiency of data capture
- improving access to data
- reducing errors and improving data integrity.

Taking each of these benefits in turn: data capture is made more efficient by capturing the data at source i.e. electronically whilst it is being generated on the site (Elzarka et al, 1997), eliminating the task of entering data from the paper form into a computer.

Access to data is improved by virtue of it being in an electronic format. Information can be searched, manipulated and electronically transferred into other applications for use by the project team (McCullough, 1993). Quality and integrity of data is improved since fewer mistakes are made in recording and mistakes made during the transcription process are eliminated (McCullough, 1997).

De La Garza and Howitt (1998) examined the use of wireless communication and computing on construction sites giving particular consideration to the trade-off between the value of transmitting the information wirelessly on demand against the cost of transmitting it. The costs of investing in wireless technology are

- purchase of hardware and software
- maintenance and upgrading of hardware
- upgrading and licensing of software
- fees of wireless service providers
- salaries of technical support staff
- training of users
- fees to a specialised wireless consultant
- integration with existing systems.

The value of having immediate access to information on site is more difficult to quantify.

- Information can be immediately fed into a collaboration tool for use by the project team potentially providing an extra day to work on the data.
- Site personnel would not have to halt operations in order to go back to the site office to obtain the most up to date information potentially saving many wasted man-hours, equipment downtime and lost productivity.
- Site personnel would always have access to the most up to date information eliminating rework due to insufficient, inappropriate or conflicting information.

However, many of the benefits of collaboration tools that are being realised by the rest of the project team will be equally applicable to the site-based team

- provides a single communication medium
- provides 24/7 access to up to date information
- reduces response times
- increases ownership and accountability
- improves record keeping and documentation
- reduces disputes and litigation.

Taking these costs, values and benefits into consideration, extending the collaboration tool out to the field seems an obvious progression but providing information technology in the harsh site environment has until now required proprietary solutions. However, with the increasing availability of mobile rugged devices and construction targeted software solutions this should no longer hinder the creation of total project team encompassing collaboration tools.

4 REQUIREMENTS FOR SITE-BASED INFORMATION HARDWARE

The construction site is a tough environment with sunlight, rain, mud and heavy handling to contend with. Manufacturers are well aware of these constraints and are providing hardware to match up to them. There are various levels of ruggedness available. A truly rugged device should have an International Protection Code rating for dust and waterproofing, and also protection from falls of at least 1m.

One of the biggest factors that will influence the choice between rugged or non-rugged is cost, with rugged devices currently costing at least 50% more than their non-rugged counterparts. However, the consequences of damaging a device in the field and losing both time and data could cost more in the long-term.

If non-rugged devices are chosen then there are suitable rugged cases to be found, but this then relies on the personnel to use the cases provided. However, be aware that some cases call themselves rugged but provide little protection.

Mobile computing hardware comes in many shapes and sizes. There are personal digital assistants, pen tablets, hand-helds and even personal digital assistants combined with mobile phones. Examples of these devices are shown in Figure 2.

Figure 2: Examples of hand-held mobile computing hardware

Previous studies (Elzarka et al, 1997) of the use of mobile information technology devices on construction sites have shown that users require the devices to satisfy the following criteria

- able to be dropped from about 1m onto a hard surface
- able to be used in the rain
- screen visible in bright sunlight and near darkness
- large buttons, if applicable
- able to be carried in one hand
- battery life of at least 8 hours.

When deciding on which hand-held device to use the following features should be considered.

- *Portability.* Is a device that fits in your pocket or in a rucksack more suitable (remember site workers tend not to wear jackets in the summer).
- *Display*. Colour displays are more pleasant to use, but monochrome screens consume much less power.
- *Batteries*. Built-in rechargables can save money, but standard alkaline batteries can be purchased anywhere - an 8hr battery life is desirable.
- *Expansion*. Important to retain flexibility - accessories include; digital camera, bar-code reader, global positioning system, extra memory and wireless connectivity.
- *Rugged.* Do site staff require a rugged device in order to ensure a longer lifespan for the equipment?

One of the most important features is screen visibility: after all if the screen cannot be read then the device is of little use. It is essential that site personnel are able to use the device both outside in bright sunlight and in near darkness. A thin-film transistor screen provides higher contrast and therefore appears brighter and easier to see. The recommended screen type for outdoor hand-held devices is a reflective thin-film transistor screen with a frontlight. Devices with wireless connectivity provide further benefits and as technologies and site applications develop progression to instant data availability and feedback capabilities will be desirable.

5 UNDERSTANDING SITE SOFTWARE NEEDS

Software applications for use on a construction site can be split into the following categories

- Computer-aided design applications
- collaboration software
- data capture
- project management
- discipline-specific applications.

Many of the benefits of these applications could be enhanced by integrating the solutions with the project collaboration tool.

The following factors should be considered in order to choose the most suitable application.

- What information do staff need/record in the field?
- Can existing information technology applications be extended to be used in the field?
- Do staff need real-time access to information, or can they simply synchronise it when they are back in the office?
- Will the palm or pocket PC operating system be used?
- What training will be required?
- What support will be available to staff?

Collaboration Software suppliers are beginning to extend key collaboration features to mobile users in the field either through their mobile phones or other handheld devices. These applications allow for example Site managers to view build programmes by plot or site and to see their daily, weekly or monthly tasks. Tasks such as call-offs, delivery confirmations and work orders can be performed whilst walking around site. Call-offs are relayed immediately to suppliers and subcontractors who respond with a confirmed delivery time. Similarly, when deliveries arrive on site, an electronic delivery note is issued, indicating a complete or partial order fulfilment.

Computer-aided design is now used on almost all construction projects to produce drawings for use in the field. However, although the drawings are produced electronically, they are printed out for use. This eliminates many of the advantages of electronic production, and reduces the opportunities for effective feedback from the field.

Data Capture on site can be used to perform Site Safety Audits (Fig. 3), Snagging, Quality Inspections, Resource Management, etc. Using a mobile device and the appropriate software almost any process that is currently performed using a clipboard and pen can be replaced.

The project management area overlaps with some of the features that collaboration tools offer. However, there are also software applications available that add project and programme management capabilities. A US consultant working on the US$440 million (£310 million) expansion of Houston's George Bush Intercontinental Airport used Primavera Systems' 'Expedition Mobile' software to provide the necessary interface between the different electronic document types used on the project.

Figure 3: A hand-held software package for site-safety audits.

Mobile applications are designed to help all members of the team to keep project information fresh, with activity progress continually updated. Using personal digital assistants, site staff can monitor the status of tasks, issue change orders or create a priority list on site without having to go back to their desks. With the ability to update project information anywhere, contractors and sub-contractors can easily communicate progress and problems (Hansford, 2001).

6 INFRASTRUCTURE CONSIDERATIONS FOR SITE COMMUNICATIONS

For many years the walkie-talkie has been synonymous with the construction industry (De la Garza and Howitt, 1998); however with the advent of mobile phones and wireless data communications there are now many more options available

- mobile phone
- wireless local area network
- private mobile radio
- terrestrial trunked radio
- low earth orbit and geostationary satellites.

Each of these will provide the technology to eliminate the time wasted on site simply travelling to and from the site office to retrieve information. The following factors need to be taken into account when implementing a solution in order to determine the most suitable technology:

- mobile telecommunications and/or access to data
- number of staff on site
- permanent or mobile site office
- site area (dimensions)
- availability of direct line of sight
- importance of certainty of cost
- coverage available from a national provider
- suitable (robust etc.) devices available for the required usage.

To enable data transfer to the operatives in the field wireless local area network or mobile telephony solutions should be considered.

7 TWO-DAY TRIAL REVEALS WILLINGNESS TO ADOPT NEW TOOLS

The technology to extend collaboration solutions out to personnel in the field is available, but there is a preconception that site personnel are not information technology (IT) literate and therefore will not be able, or willing to, take full advantage of the benefits that collaboration tools bring the 'upstream' project team.

At the beginning of March 2002, a two-day event, to raise awareness of mobile technology and its potential uses in construction, was held at the headquarters of the M6 Toll Road project. The contractor consortium CAMBBA (Carillion, Alfred McAlpine, Balfour Beatty and Amec) hosted the event on site. The event consisted of two parallel activities, a series of presentations and demonstrations were open to all site personnel throughout the two days whilst a series of usability trials were carried out on four hand-held devices with 17 construction worker volunteers (Fig. 4).

Figure 4: One of the usability trial participants

On a construction site there are several different roles that involve different skills and hence different types of people. They each have different levels of IT literacy, and differing perceptions of the applicability of IT use in the field.

To understand whether different devices would suit the different people and tasks, representatives from each of the user groups identified below performed the usability tests

- agent
- section engineer
- site engineer
- works manager/foreman
- health and safety/environmental adviser.

Following a desk-based study of current devices on the market it was decided to trial the following

- Itronix FEX21 - indoor screen
- Sagem WA3050
- Symbol PPT8100
- Casio IT 700

These provided a range of different sizes, functionality, ruggedness and screen types. The Itronix device acted as a demonstration of the use of an indoor specification screen outdoors.

Each participant performed the following construction based tasks using different applications on each of the four devices in a random order.

- Find out the width of room 1 on a house plan and annotate with the correct dimension (application - PocketCAD).
- Find out how thick the backfill layers should be in the reinforced earth wall from a Method Statement (application - eReader).
- Enter the details of a concrete pour into a site diary (application - Outlook).
- Complete a quality inspection on a catchpit using the inspection test sheet form (application - PocketPC Creations).

The participants were also asked to assess the portability, screen clarity, appearance, ease of data entry, and input keys on each device. To gain realistic results, the participants were tested whilst in their everyday situation

- the trials took place outside
- all participants wore helmet, coat and boots
- the weather was cold and sunny with showers
- all participants were standing.

Taking into consideration age, job type and previous information technology experience, the usability trials set out to discover if construction workers would be happy to use a hand-held device for their work and which device they preferred.

The results were very encouraging with fifteen (88%) of the participants confirming that they would be happy to use one of these devices for their work. There was no significant variation across age, job type or information technology experience, and interestingly contrary to commonly held beliefs the foremen and works managers were most enthusiastic. Typical comments were “superb”, “very powerful”, and “definitely see an advantage”. However, these comments were tempered by the barriers of cost and training, and many participants reiterated the need for proof that the devices would be cost-effective, and that usable, useful applications would be the key differentiator.

A total of 82% of the participants had never used a hand-held device, and two (29%) had never even used a computer before. Nevertheless, considering that there was only a 10 minute training session prior to the trials, the participants were able to complete 79% of the tasks.

When asked how the devices could be improved for use by the construction industry many of the participants recommended that the devices should be more rugged – dust, water and shock proof. They particularly thought that the screen should have some form of cover. However, this conflicts with the result that eight (47%) of the participants preferred the Sagem WA3050 that was the only non-rugged device. Perhaps this indicates that manufacturers should be aiming to cut down the size and weight of rugged devices if possible.

Other interesting results of the trials were

- 14 (82%) preferred a colour screen
- 12 (71%) thought that combining the device with a mobile phone is a good idea
- screen size was not thought to make much difference: clarity was more important.

8 LIMITATIONS OF EXISTING INFORMATION TECHNOLOGY

The following barriers were identified by the participants during the trials.

- Many found the stylus too small to handle with larger hands and potentially having to wear gloves too.
- You may become too reliant on the device, such that if it were to break down you would have to go back to pen and paper and the necessary protocols would no longer be available.
- If the device broke down you could lose all of the work that had been carried out since the last synchronisation. This could however be overcome by saving the data onto a removable disk that could the data could then be retrieved from and if necessary uploaded onto a new device.
- It was thought that the screen size available was impractical for viewing drawings, and many would prefer to stick to A2 paper copies to carry out drawing based tasks.
- Manual data input using either the stylus or the pop-up keyboard was found to be time consuming. This indicates that manual input should be minimised through the use of drop-down menus and pre-written text.
- It was thought that the costs involved in purchasing a device would outweigh the benefits gained. At approximately £1200 for a rugged device many participants thought that management would have to be convinced that purchasing these devices was worthwhile. But potentially these devices could replace the provision of desktop computers to some operatives. This would provide savings both in terms of the equipment and also the security provisions that are made.
- Attitudes towards the devices and information technology in general could be a barrier, one participant commented ‘Ought not to underestimate people, could just pick up a telephone instead’.
- Battery life should be considered. With staff working a 10-12 hour day in the summer the inconvenience of running out of battery whilst out on site could create reluctance to rely on the device.
- The devices were perceived by some participants as a gimmick or a toy, and it was thought that they should only be used when appropriate rather than as standard.

8 PERCEIVED BENEFITS OF USING INFORMATION TECHNOLOGY

Although the barriers given above were identified there was a general level of enthusiasm for the future use of similar devices on a construction site. This is illustrated by the benefits that the participants identified during the trials.

- The information is less subjected to the elements, unlike paper, which can get wet and blows around in the wind.
- The information is easy to carry, rather than having a lot of paperwork 'filed' in the back seat of the pick-up truck.
- The tedious task of typing up notes when you are back to the office is eliminated by collecting data electronically in the field and then synchronising it back to the site data network.
- It could provide a useful reference tool so that you do not have to remember or predict what information you will need to view/record in the field.
- It could enable engineers to spend more time actually out on site.
- Data collected in the field will be more structured and consistent.

There are also further benefits for the project team as a whole that result from having instant access to well-structured data.

- Information collected in the field can be immediately passed on to other members of the project team.
- Data can be imported into, and manipulated using, other software packages.
- Data can be easily searched in the future both for auditing purposes and for future knowledge management applications.

9 THE NEXT STEP

This paper has illustrated that many of the perceived barriers to the uptake of handheld devices in construction are either non-existent or can be easily overcome. However, there are currently very few construction teams realising the full potential of their use.

In the future mobile technology will enable collaboration on several different levels (Fig. 5) extending the use of extranet-based collaboration tools into the field.

- *Site to site.* Information can be rapidly exchanged by personnel out on site, often in conditions where more traditional methods of exchange are not viable. For example speaking above the noise of an active piling rig or attempting to pass paper-based information will often entail interrupting the activity in progress.
- *Site to site office.* Site based personnel will no longer need to return to the site office in order to obtain further information that they require or that they have been requested to provide. Time-savings in this case could be in the order of several hours per person each day.

- *Site to project team.* The office based project team are able to communicate directly with personnel on site often allowing the immediate resolution of construction difficulties. This collaboration can also take place in reverse allowing site-based personnel to provide immediate feedback to the project team resulting in more efficient and appropriate solutions.

Figure 5: Collaboration opportunities

Besides the information-based benefits there will be an additional benefit that has the potential to outweigh these. Through access to collaboration systems site personnel will begin to feel less isolated from the project team, which will result in greater cooperation, mutual understanding, enhanced team relations and consequently better quality projects.

10 CONCLUSIONS

There are many different mobile devices and software solutions to choose from to extend collaboration tools for use by site based personnel. Contrary to common perception site based staff are ready and willing to use these devices to communicate with the wider team.

The information needs of site-based staff will differ from those of the rest of the project team not only due to their particular role but also the physical and technical constraints of receiving and sending information from site. Collaboration tool providers must take this into account. It is imperative that the introduction of information technology solutions for field based staff does not produce yet more incompatible applications in the construction industry but that they integrate with existing project wide collaboration solutions in order to reap the benefits they provide.

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APPENDIX 2: PAPER 2

FULL REFERENCE

Bowden, S.L., Dorr, A., Thorpe, A. and Anumba, C.J. (2005). Making the case for mobile IT, *Proceedings of the International Conference on Computing in Civil Engineering "Dare to Think Outside the Box; Push the Envelope; and Present the Future in Computing in Civil Engineering"*. Cancun, Mexico. July 12-15, 2005.

ABSTRACT

The construction industry is typically characterised as being slow to change and to adopt new information technologies. Mobile technologies have been no exception; the primary reasons given for this hesitancy are the perceived lack of return on investment and an absence of industry-specific examples of successful adoption. A series of eleven case studies have been undertaken to facilitate the removal of these barriers. The case studies, detailed in this paper, were selected to demonstrate the use of mobile technologies by point-of-activity workers in construction, their influence on process efficiency, improved opportunities for data collection, and that rapid return on investment is usually achievable. The analysis identifies generic benefits of the applications and the lessons learnt provide clear guidance that should help ensure mobile technologies are appropriately deployed in construction. This paper concludes that the successful implementation of mobile technology typically produces a return on investment within one year of adoption, regardless of the initial set-up costs, and that the adoption of mobile technologies can make a significant contribution to the ongoing drive for process improvement. As such, they are a valuable tool to reduce some of the unnecessary costs currently inherent in construction projects.

1 INTRODUCTION

There is general agreement that the construction industry's uptake of innovations in construction IT is disappointing, particularly when considered in relation to the huge research effort and expenditure being invested in this field (Anumba 1998). This holds equally true for the mainstream use of mobile technologies. Although the first rugged hand-held computer was developed in 1981, researching the use of mobile computing in construction only began in earnest in the mid-nineties (Alexander 1996, Cox and Issa 1996, Liu 1995, McCullouch and Gunn 1993). This was probably spurred on by the introduction of the Apple Newton MessagePad in 1993; the first PDA (Personal Digital Assistant). This device was withdrawn due to commercial reasons in 1998, though it was soon replaced by the plethora of hand-held computers that are now available.

Research into the potential uses of mobile technologies in construction continued, with potential applications including: site diaries (Scott and Assadi 1997), maintenance conditions (Rojas and Songer 1997), progress records (Cox et al. 2002), and monitoring piling activities (Ward et al. 2003). However, mobile extensions for well-known construction software have only recently become available (e.g. PocketCAD and Primavera Field Manager) and implementation of mobile solutions on site in the UK is still predominantly at the trial stage.

It is assumed that the barriers to the mainstream uptake of mobile solutions in construction are those commonly cited as barriers to the uptake of construction IT solutions in general, namely; the low level of perceived benefits from IT investments amongst construction business managers (Andresen et al. 2000), the process of investment justification (CIRIA 1996) in an industry with generally low profit margins, a lack of awareness about information and communication technologies (Love and Irani 2001) and the lack of exemplars demonstrating its successful use by others (Anumba 1998).

It has been recognized that case studies have a major role to play in increasing industry uptake of construction IT solutions (Bloomfield 1998). They can provide industry with examples illustrating where mobile technology has been successfully adopted and details of the costs and benefits involved.

This paper documents the research undertaken to address these barriers and presents a cross-case analysis covering the findings from eleven descriptive case studies. Each case study evaluated the application of a mobile IT solution within a construction company by covering the process that was enhanced, including both the direct and indirect users of the information generated in the process as the unit of analysis (Figure 1).

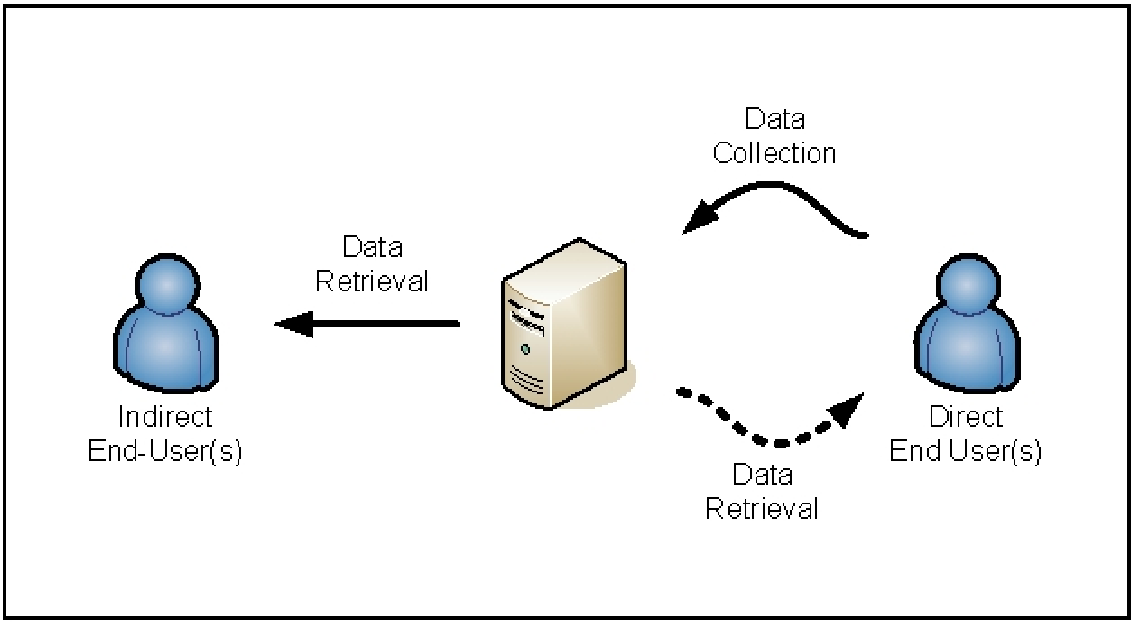

Figure 1: Unit of analysis

The cross-case analysis starts by clarifying the theoretical framework underlying the data collection for the nine "successful" case studies by using replication logic. It then presents the case study data analysis which concludes by detailing the evidence for the research questions that were defined at the outset of the evaluation, prior to conducting the individual case studies. Comparison is made with two further case studies that were selected to understand why some mobile IT solutions fail using theoretical replication.

2 The COMIT Project

The COMIT project was formed to understand which applications mobile IT is most suited for and to encourage its adoption in the construction industry. It is a two-year research and development project funded by the UK's Department of Trade and Industry led by Arup, in partnership with BSRIA and Loughborough University.

A reason often given by industry practitioners for the low uptake of construction IT innovations is the mismatch between the research undertaken and the needs of the construction industry (Anumba 1998); therefore a key project activity was the formation of the COMIT community representing the major stakeholders: construction and engineering companies, technology providers, research and development institutions and dissemination companies. The community, which comprises 50 organisations, provides the research team with guidance and input to ensure industry relevance.

The primary objectives of COMIT are to:

- Document existing applications of mobile IT in construction
- Create a better understanding between technology and construction companies
- Understand which applications will deliver business benefits
- Create wider awareness of the benefits of mobile IT in construction

This paper focuses on the first objective: to document existing applications of mobile IT in construction.

3 Case Study Design

3.1 Selection of a research design

Several research methodologies can be used to study the implementation of IT solutions within an organization: experiment, surveys, action research and case studies (Yin 1994). One of the principal purposes of the methodology is to help avoid a situation in which the collected data does not address the initial research questions. Therefore, it is necessary to look first at the purpose of the research before determining the methodology: “The utilisation of mobile technologies by point-of-activity workers in construction increases the efficiency of the process, resulting in improved data collection and hence a rapid return on investment.” This leads to several research questions:

- What are the benefits of a mobile IT solution?
- How is the previous process altered? Is it simply replicated incorporating mobile IT or is it re-engineered?
- Does it matter who championed the introduction of mobile IT?
- What training was undertaken and how does this affect the implementation?
- What other factors will influence successful implementation?
- Does the introduction of mobile IT always result in a return on investment?

The multiple case study approach was selected because of its high exploratory potential (Yin 1994), the limited number of example applications to study (Eisenhardt 1989), the qualitative data required (Blismas 2001), the focus on contemporary events, the need to study the application in its context (Benbasat et al. 1987), and the ability to provide descriptive examples for industry use.

3.2 Case Study Protocol

A case study protocol was developed to increase the reliability of the case study research; this was especially important as there was a team of three investigators. It provided an overview of the case study objectives, the data collection procedures and a template for the single case study reports. The case study protocol was reviewed to ensure that the information to be collected was relevant and satisfied industry needs.

3.3 Case Selection

A literature review was conducted to evaluate the extent of mobile IT adoption on construction projects. As part of the initial screening process an “existing use” was prepared for each proposed case study (see www.comitproject.org.uk for examples). This set out the business problem and solution, details of the hardware and software used and the project location. The list of “existing uses” was reviewed and six were selected for full case study development. These were chosen on the basis of a UK location, and to provide a variety of processes and technologies.

In addition, the opportunity to explore two cases of the use of mobile telephone applications in Finland was presented by VTT (including one that was only partially successful), and three cases of the use of mobile IT within Arup were also investigated as these provided one “unsuccessful” case and two studies utilising different technologies; GPS in combination with a PDA application and BlackBerry. Table 1 summarises the basic characteristics of the eleven mobile IT applications: ID, process, hardware, software, and infrastructure.

Table 1. Eleven case study mobile IT applications.

ID	Process	Hardware	Software	Infrastructure
A	Preventative maintenance	PDA, RFID tags	Off the shelf	Synchronisation
B	Job allocation & timesheets	PDA	Customised	Mobile phone network
C	Defect management	PDA	Bespoke	Synchronisation
D	Fleet management	GPS vehicle tracker	Customised	Mobile phone network
E	Management of piling works	Tablet PC	Bespoke	Wireless LAN
F	Defect management	Digital pen & paper	Bespoke	Mobile phone network
G	Managing site safety	Mobile phone	Customised	Mobile phone network
H	Timesheet & payment	Mobile phone	Bespoke	Mobile phone network
I	Earthworks examinations	PDA, GPS tracker	Bespoke	Synchronisation
J	Email & PIM	BlackBerry	Off the shelf	Mobile phone network
K	Field observations	PDA	Bespoke	Synchronisation

4 COLLECTING THE DATA

For each case study, the investigator conducted a site visit to observe the mobile solution in use. Interviews were undertaken with the direct end user(s), the indirect end user(s), and the software providers (either the IT division within the construction company or an external provider). Any relevant documentation such as project procedures, software specifications and publicity material was also collected. This provided mainly supplementary data, used to triangulate and extend the interview data.

Upon completing the site visits, the materials for each case study were collated and individual case study reports compiled. These were reviewed for accuracy by the original contributors. Industry relevance was ensured through consultation with the COMIT community. Although the two less successful cases (H and K) provided valuable lessons learnt material, these were not published in the same format for confidentiality reasons.

5 CROSS-CASE FINDINGS

The main purpose of the cross-case analysis was to provide answers to the research questions outlined above. This section reviews each of these in turn and presents the findings from the analysis. In the analysis, the definition of a successful solution is given as a mobile IT solution that has continued following the initial pilot implementation and either been further enhanced or rolled out to be used on other projects or areas in the business.

5.1 Benefits

It is commonly accepted that the use of IT will eliminate many of the problems associated with paper-based documentation: duplication, feedback, quality, exchange, awareness, illegibility, format, volume, cost, queries, and "out of date" (Murray and Thorpe 1996). These benefits are also apparent in the implementation of mobile IT solutions in construction and can be broadly categorised as follows: improving efficiency of data capture, improving access to data, reducing errors and improving data integrity. Each of these benefits is examined in turn.

Data capture is made more efficient by capturing the data at source, i.e. electronically whilst it is being generated on the site (Elzarka et al. 1997), eliminating the task of keypunching data from the paper forms into a computer (McCullough, 1997). The majority of the case studies exhibit this benefit. By capturing the data at source using a mobile computing device (PDA, BlackBerry, Tablet PC or Digital Pen) the process of typing up this information for subsequent use is eliminated. Due to the time required for this activity this information was often left in a paper-based format; therefore the capture of electronic data at source has improved access to data.

Case D exhibits this benefit to a greater extent as the information required is collected automatically with no need for human intervention. The GPS tracker box installed in each van records the van's position, direction, speed, distance travelled and whether the engine is running. This information is then transferred on request to the central database via the mobile phone network.

Case H exhibits this benefit, however, due to the very limited user interface (SMS on a mobile phone with no prompts), the users themselves have found this method of data collection to be inefficient and have reverted to entering the data on an extranet site when they return home.

Case J exhibits this benefit to a limited extent as users would not tend to handwrite an email in the field and then type it up on their return to the office. However, they then rely on their memory to remember to send the email, or enter the appointment at a later time.

Access to data is improved by virtue of it being in an electronic format. Information can be searched, manipulated and electronically transferred into other applications (McCullough, 1993). This benefit is exhibited by all of the case studies (Table 2). For a two-way data process this improved access to data benefits both the direct end-user and the indirect end-users, whereas for one-way data processes only the indirect end-users benefit.

Table 2. Benefits derived from improved access to data.

		Case Study ID										
	Benefit description	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Indirect	Reports produced quickly & easily	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
	Better customer service	Y	Y	Y	Y	Y	Y	Y			Y	Y
	Identification of trends			Y	Y	Y	Y	Y	Y	Y		
	More efficient task allocation	Y	Y	Y	Y					Y	Y	
	Reduced task turn-around time			Y	Y		Y	Y			Y	
	Improvements in quality of work			Y		Y	Y	Y		Y		
	Increased accountability of staff				Y		Y	Y	Y			
	Reduced supervision					Y				Y		
	Track stolen equipment	Y			Y							
Direct	Task instructions available	Y	Y			Y		Y		Y	Y	
	More efficient use of time	Y								Y	Y	
	Avoidance of work duplication	Y		Y		Y				Y		
	Better customer service										Y	

Mobile applications enable information to be transferred from the field back to the office much quicker than the previous paper-based systems; the studies show that this transfer time could be reduced in some cases by as much as three weeks. This ensures that the indirect end-users have access to more up-to-date information which in turn leads to the following benefits:

- Improvements in the quality of work e.g. Non-conformances are detected earlier, which leads to more cost-effective intervention.
- More efficient task allocation e.g. Maintenance is now proactively scheduled based on location and urgency rather than reactively.
- Reduced task turn-around time e.g. Defects are almost immediately reported to the sub-contractors who can then begin to rectify them; days rather than weeks later.
- Better customer service e.g. Clients can see on the extranet the current status of jobs as soon as the information is collected on the PDA. This is a huge improvement over the previous three week time-lag.

- Reduced supervision e.g. Regular site visits are no longer necessary to ensure that the inspections are being carried out correctly. Discrepancies in inspection methods can be spotted early and corrected from the office.

Mobile IT facilitates the collection of data electronically at source rather than collecting that data on paper forms, or in some cases not at all. It also enables the information to be collected in a more structured format (see improving data integrity below). This in turn leads to the following benefits:

- Reports produced quickly and easily e.g. Reports can be produced and distributed immediately, detailing all of the defects allocated to a particular sub-contractor.
- Identification of trends e.g. A central management system enables safety to be tracked across all projects. Subcontractors who are consistently causing safety incidents can be highlighted and dealt with accordingly.
- Increased staff accountability: The GPS location data collected ensures that employees no longer use company vehicles for personal use.
- Tracking of stolen equipment e.g. RFID tags connected to the equipment can be used to identify it if stolen.

In the case of two-way data transfer processes, current and historical information can be provided at the point of activity to the direct end-user. This results in the following benefits:

- Task instructions available e.g. Work orders are received at the point of activity eliminating the need to go to the office for instructions.
- More efficient use of time e.g. Users are able to convert what was previously downtime away from the office into productive time, to respond to key emails immediately, and to manage their email more effectively.
- Avoidance of work duplication e.g. Employees can now see from the central system if the snag records are being used, thus removing the possibility of two people checking the same snag at the same time.
- Better customer service e.g. Relationships with overseas clients are improved as employees can easily remain in contact with them without having to stay in the office late.

Quality and integrity of data is improved since fewer mistakes are made in recording and mistakes made during the transcription process are eliminated (McCullough, 1997). This leads to a significant reduction in administration time, made possible through the following enhancements:

- Calculations can be automated
- Dropdown lists force the selection of predetermined data
- GPS can provide accurate location information
- Certain field entries can be automated e.g. job-number, time and date
- Field entry data types can be set e.g. only a 3 digit number can be entered
- The user can be prompted to complete certain activities e.g. to take a photo

5.2 Process Reengineering

Reengineering is defined as the "fundamental rethinking and radical redesign of business processes to achieve dramatic improvement in critical, contemporary measures of performance" (Hammer and Champy 1993). Information technology (IT) is regarded as the essential "enabler" of reengineering (Chan and Land 1999).

A process should be viewed as a group of activities that create value for the customer. By definition process innovation or reengineering involves creating and putting into practice something new. It should not be confused with process improvement which is incremental and takes the existing process as given (Vedpuriswar 2003). The case studies of the implementation of mobile IT all illustrate process improvement rather than process innovation or reengineering. The primary process changes implemented are the removal of non-value adding activities (e.g. travelling to and from the office to collect information), the capture of information once only and at source, and the automation of certain activities (e.g. the production of reports). However, some cases illustrate the beginnings of empowerment of the workforce; site supervision can be reduced by providing information directly to the site worker.

The implementation of mobile IT has not been seen as an opportunity to innovate, simply to improve existing processes. As the technology becomes more commonplace in the construction industry, enabling the point-of-activity workforce to participate in the information flow within a project, there may be a drive to empower the workforce further and hence rethink the current processes. For example, if there is a problem on site, should the point-of-activity worker be able to contact the designer directly in order to resolve it?

5.3 People Issues

It must be borne in mind that it is useless and costly to implement high-tech I.T. systems without also addressing human resistance and training issues (Moniem 2000). Stewart (2004) provides a summary of the barriers and coping strategies that have been identified as being present in the context of IT implementation in the construction industry. People issue barriers include lack of IT leadership, fear of change and uncertainty and low technology literacy of some participants. The coping strategies were identified as: appoint a project IT champion, adopt IT-related applications with short learning curves, and allocate resources to IT training. These issues were explored in the case studies.

All of the case studies were able to identify a champion at a senior level (e.g. Operations Executive/Director). However, in case K, although the initial drive to implement a mobile solution came from the Technical Director, his subsequent involvement was minimal and the ongoing management was the responsibility of the IT Operations Manager. There was little effort made to make one individual fully responsible.

The training required in most cases was minimal, ranging from a few hours to 3 days. It was felt by the implementation teams that this was sufficient since the applications had been built to replicate the existing forms and processes, thereby shortening the learning curve. However, the direct end-users in some cases wished that there had been more comprehensive training. The majority of case study participants cited a user friendly interface that was quick to learn as key to the successful adoption of the solution. This is particularly important in applications where the end-users are constantly changing e.g. when they are sub-contractors or agency staff.

5.4 Other Factors Influencing Success

Before a new system can be devised, the existing systems and the interactions between these systems must be fully understood (Caldwell, 1994). Some poor management practices include not determining users' needs properly and not defining a project's scope accurately (Chan & Land 1999). This is apparent in case K which ultimately resulted in an aborted project. The key-stakeholders only met mid-way through the project when it was clear that they had different priorities and objectives. The management wanted an easy solution to save vast sums of money with minimal expenditure and little overhead. The field engineers wanted the PDA to satisfy every issue that they had in the field, and the IT department wanted the project to prove the hidden worth of the technology (Bell 2003). These differences were not addressed resulting in the development of a solution without fully understanding the users' needs.

It was not until the final review meeting, that an understanding of the existing process was gained. Up to this point, assumptions on the level of usage were made by the IT group. However, subsequent analysis showed that all pilot users (apart from one) only made observations on an ad-hoc basis, typically once a week. This level of usage did not warrant the implementation of the solution as little efficiency gains would be made.

The other factor common to both unsuccessful implementations was the form factor of the device selected not being suitable for the data collected. In case K, there was a requirement to input paragraphs of unstructured text using character recognition or the virtual keyboard on the PDA. For H, the requirement was to edit an SMS message inputting a long list of different types of hours worked. In both cases users found it easier and more efficient to input data to the application provided on their PC using a keyboard.

5.5 Return on Investment

The effective use of information technology is seen by many as the key differentiator between the successful enterprise and the mediocre, although it has always been difficult to demonstrate the actual added value of IT investment. However, this situation is no longer acceptable in the present competitive global environment, with management facing strong and increasing pressure to cut costs and increase margins, even the most essential IT investment comes under scrutiny (Remenyi et al. 1998).

If construction companies are to embrace the concepts of process improvement, it is vital that the business benefits it provides can be clearly demonstrated (Finnemore and Sarshar 2000). Research indicates that many managers are reluctant to invest in innovation and of those that do, they usually provide limited strategic planning and support to ensure its efficient implementation. The reasoning for this reluctance to invest in IT may stem from a lack of proven return on investment of IT expenditure, and a project focus that seeks to achieve the full return on process investment from single projects (Stewart et al. 2004). This sentiment was echoed by the COMIT community who thought that quantified cost and benefit data would be the key information provided from the case studies.

The costs of implementing the mobile IT solutions ranged from £7,400 (A) to £135,000 (B), with an average cost of £45,000. These costs included upfront investigation costs, the mobile computing devices, the software application (licence fees and development time), the communications infrastructure (i.e. how the data is transferred to the back-office system), the data storage system, consultancy, site installation, training, staff time and ongoing support.

The time taken to return on investment ranged from four months (J) to twelve months (A, E, F and I), with an average of nine months. In most cases a formal analysis of return on investment had not been completed by the project team, however, benefits such as reduced administration time and a reduction in administration staff required could be quantified and balanced against the costs incurred.

Case K was able to calculate their payback period very easily as the inspection work was subcontracted and the fees paid to the sub-contractors had reduced from £1,100 to £350 per route mile. Case E recorded the percentage reduction in remedial work (75%) which equated to a potential saving of £385,000 per annum if the system were to be used throughout the company. All the successful case study participants agreed that the costs incurred were small in comparison to the potential benefits, especially if harder to quantify benefits, such as improved customer service, were also taken into account.

6 CONCLUSIONS

The conclusions drawn here relate back to the initial research proposition; "The utilisation of mobile technologies by point-of-activity workers in construction increases the efficiency of the process resulting in improved data collection and hence a rapid return on investment."

All of the applications had achieved process improvement by eliminating non-value adding activities, capturing information once only at the source, and/or automating certain activities. However, the process improvements achieved in the unsuccessful cases were not sufficient to offset the costs incurred. This was due to the lack of volume of information collected and the difficulty in entering the information required, which stemmed from a lack of understanding of the initial process and/or the users' needs. The successful cases covered a wide range of processes, all of which were collecting structured data and in each case return on investment was achieved in less than twelve months.

In order to achieve a successful implementation and hence a rapid return on investment the following lessons can be learnt from this study. It is important to:

- Have ongoing involvement of a senior executive to champion the technology;
- Have early involvement of the users to fully understand their needs and develop a sense of ownership of the solution;
- Undertake upfront process analysis to understand the data collection requirements;
- Choose the most suitable user-interface, and hence device, for the users' data collection and retrieval activities;
- Develop a solution with a short learning curve and provide sufficient training.

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APPENDIX 3: PAPER 3

FULL REFERENCE

Bowden, S.L., Dorr, A., Thorpe, A. and Anumba, C.J. (2004). Mapping site processes for the introduction of mobile IT, *Proceedings of the European Conference on Products and Processes Modelling (ECPPM 2004)*. Istanbul, Turkey. September 8-11, 2004, pp 491-498.

ABSTRACT

Due to its nature, the construction industry requires its personnel to be mobile, to communicate efficiently and to exchange, analyse and synthesise large volumes of information. The construction industry's drive towards utilising IT to enhance communication, both within a company and between clients, consultants, contractors, subcontractors and suppliers, has, to date, largely ignored the need to deliver information effectively to mobile personnel e.g. whilst on site or attending a client meeting. The advent of suitable devices and software solutions will go some way to correct this. However, simply because the technology is now available it should not be indiscriminately applied. This paper documents activities undertaken to better understand which construction processes would derive most benefit from the application of mobile information and communication technologies. The approach taken also illustrates how these processes linked together thus providing an optimum implementation plan for mobilising site-based processes. This research forms part of a larger study (known as COMIT).

1 INTRODUCTION

Construction affects the overheads of all industrial and commercial activities, and the international competitiveness of all industries can be improved through better construction productivity and quality.

In order to genuinely improve construction project performance against key criteria of time, cost, quality, safety, the environment and respect for people, the organisations in the construction supply chain need to become more integrated through increased internal and external collaboration.

Collaboration requires communication and mobile, point-of-activity, digital tools clearly can make a significant contribution to improving project performance. Computer tools have already changed the ways buildings are designed, procured and constructed, but now communication and knowledge-sharing techniques at and between points of activity offer further potential for increased productivity, faster construction, higher quality, and lower cost.

Currently, many people in the construction industry are prevented from efficiently and effectively contributing to the information flows that are crucial to any business. Error rates in data collection are high; the speed and immediacy of data receipt, capture and feedback require significant improvement; information exchange is expensive; and audit trails are by no means automatic. Delays, variable productivity, accidents, and quality problems are therefore commonplace (Egan, 1998).

The development of affordable mobile technologies has enabled their deployment across all sectors of industry and commerce. From bar codes on the weekly shopping to hospital consultants recalling a patient's records using a PDA, the ability to capture, store and re-use information by a mobile user is now commonplace.

Although the European construction industries are the largest industrial cluster in the European Union, representing 11% of total gross domestic product (GDP) with an annual turnover of £520 billion and a quarter of all industrial output, this sector is still an immature market for mobile technology solutions providers.

The recent advances in technology have increased the performance and reduced the price of many mobile computing devices, resulting in renewed interest in their potential application in the construction process.

2 THE COMIT PROJECT

The COMIT project, Construction Opportunities for Mobile IT, was formed to address the issues outlined above. COMIT is a two-year research and development project funded by the UK's Department of Trade and Industry led by Arup, in partnership with BSRIA and Loughborough University.

A key element in the project is the formation of the COMIT community which is formed of representatives from the key stakeholders:

- Construction and engineering companies
- Technology providers
- Research and development institutions
- Dissemination companies

The community, which comprises 50 different organisations, provides the research team with guidance and input to the deliverables, making sure they are providing what is needed.

The primary objectives of COMIT are to:

- Document existing applications of mobile IT in Construction
- Create a better understanding between technology and construction companies
- Understand which applications will deliver business benefits
- Create wider awareness of the benefits of mobile IT in construction

This paper focuses on the third objective: to understand which applications will deliver business benefits.

This activity provided the COMIT community with a mechanism to decide on which processes should be implemented on real construction projects (the "demonstration projects") in order to verify the theoretical benefits that were postulated.

3 INFORMATION NEEDS OF MOBILE PERSONNEL

There have been many attempts to categorise and identify construction information. Researchers have filtered site information to a greater or lesser extent, from a high-level division into technical, commercial, management and control (BT, 1995) to a more detailed level where different types of documentation are classified, e.g. technical queries, dayworks, requisitions, and method statements (Murray & Thorpe, 1996), to classification by job-type (Tenah, 1986).

Bowden (2002) conducted a survey of site-based personnel which concluded that they are both recipients and producers of paper-based information. The paper-based tasks that they carry out in their normal work are numerous (85 different tasks were identified). These were grouped into different document types revealing the most commonly identified tasks as completing data collection forms (25%), dealing with correspondence (18%), viewing and reviewing drawings (13%) and reading and writing specifications (6%).

It was shown that the documentation to which site-based personnel would like to have access in the field is related to the paper-based tasks that they carry out as part of their normal work. This provides support for Tenah (1986) who found that information needs are inextricably linked to the management responsibilities of each member of the project team. The survey results showed that the document types site-based personnel would find most useful to have access to/record in the field (out of the office) were drawings (24%), data collection forms (12%), correspondence (8%), progress information (7%) and specifications (7%).

4 MOBILE IT APPLICATIONS

Since the late 1980's, both the academic and industrial sectors have been investigating the use of mobile IT for developing applications used in field data collection. Researchers have looked at the application of mobile IT to the following processes:

- Progress records (Cox et al., 2002)
- Site diaries (Scott, 1990)
- Resource management (McCullouch & Gunn, 1993)
- Construction documentation (Williams, 2001)
- Quality inspections (Cox & Issa, 1996)
- Maintenance conditions (Rojas & Songer, 1997)
- Snagging/Defects management (Mobbs, 2002)
- Health and safety (Hawkins, 2002)
- Site design problem resolution (Liu, 1995)
- Monitoring piling activities (Ward et al., 2003)

The benefits identified by this research can be broadly categorised as follows (Bowden & Thorpe, 2002):

- Improving efficiency of data capture
- Improving access to data
- Reducing errors and improving data integrity

However, it is clear that for any proposed system to be acceptable it has to be technically, economically and operationally feasible. For a system to be economically viable, the cost savings must be sufficient to justify the investment concerned and pay back the investment within a realistic time-span given the technology involved and the business environment concerned (Baldwin et al., 1994).

5 PROCESS MAPPING

Many people have argued that construction products are one-off with each project being unique – however, the same underlying procedures and processes are adopted time and again (McConalogue, 1999). The quality, quantity and timing of information can either hinder or facilitate the successful completion of projects. It has been suggested that the cost of construction can be reduced by 25% through the efficient transfer of information (Davidson & Moshini, 1990).

To fully understand these construction procedures and processes and to identify the opportunities to increase the efficiency of information transfer, a consistent approach must be utilised. "Process Mapping" is a management tool initially developed and implemented by General Electric as part of their integrated "Work-out," "Best Practices," and "Process Mapping" strategy to improve significantly their bottom line business performance (Hunt, 1996).

There have been many research projects investigating how to map construction processes (Baldwin et al., 1999). Numerous systems are available, these include:

- Petri Nets
- Function Decomposition
- Structure Charts
- HIPO Diagrams
- Warnier-Orr Diagrams
- Action Diagrams
- Decision Trees
- HOS Charts
- IDEF0
- Entity Relationship Diagrams
- Data Flow Diagrams

Karhu (2000) provides a comparison of six commonly used methods; scheduling method, simple flow method, IDEF0, IDEF0v, IDEF3 and Petri Nets. He concludes that these process modelling methods have been developed for specific purposes. Therefore, a more general method is required that eliminates the difficulties associated with the process model graphical representations being too complicated for the employees involved within the process to interpret and hence make meaningful contributions.

6 METHODOLOGY

To identify which construction processes would benefit most from the introduction of mobile IT, the following four stage approach was adopted (see Figure 1):

- Stage 1: Identify ten processes to look at in further detail
- Stage 2: Map out the “As Is” process for each of the ten
- Stage 3: Map out the “To Be” process for each of the ten
- Stage 4: Select four processes to be implemented on the demonstration projects

Each of these stages is discussed in further detail below.

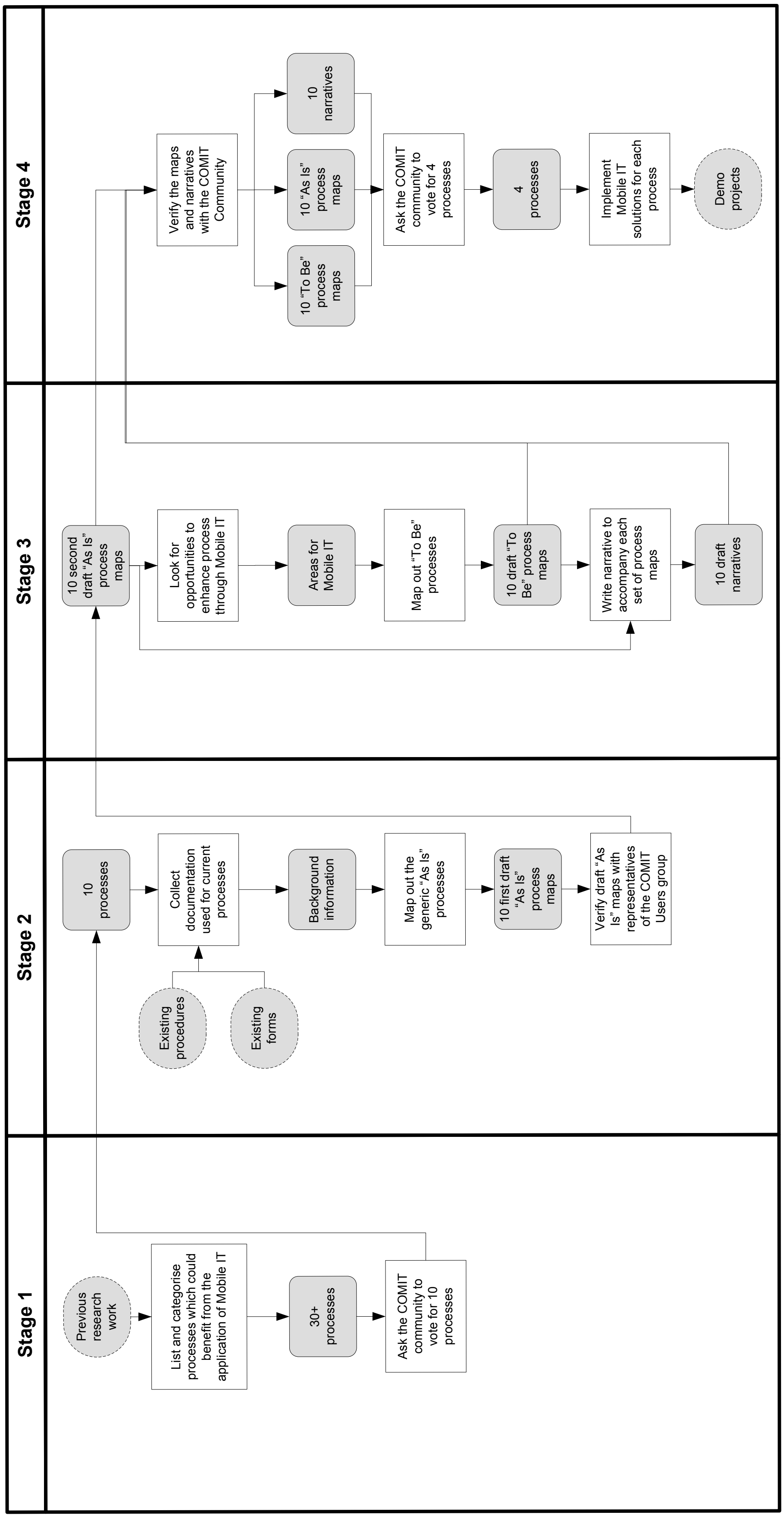

Figure 1: Research methodology

6.1 Stage 1: Identify ten processes

The research team conducted a literature review to identify which construction processes could be suitable for the introduction of mobile IT and which technologies would be applicable. These processes involve personnel working away from their desks and/or the transfer of information from that point-of-activity. The processes were categorised into:

- Communications (e.g. design professional to foreman)
- Data capture (e.g. goods received notes)
- Identification (e.g. accounting for equipment/materials on site)

The COMIT community was presented with a list of thirty processes and asked for any additional processes they might wish to include. They then discussed which processes they thought had most potential. Finally, they voted for their top ten processes. This resulted in the following ten processes being selected to be investigated further:

- Goods received notes
- Drawing distribution and usage
- Task allocation
- Monitoring progress
- Monitoring health and safety on site
- Quality inspections
- Site design problem resolution
- Site diaries
- On-site accounting of operatives/visitors
- Maintenance inspections

6.2 Stage 2: Map out the "As Is" processes

The primary objective of the process maps that were developed was to present an illustration to the COMIT community of the possible efficiency gains mobile IT could provide in order that the community could determine which processes should be selected for implementation on the demonstration projects. Hence, it was decided that a simple graphical representation, readily understood by construction professionals, should be used.

As these maps were to be developed by several parties and it was vital that they should be in standard format to enable comparison by the COMIT community it was decided that a suitable software product should be found. This product should also provide the capability to publish the maps on the Internet so that the maps could be viewed and used by anyone without the need for the process mapping software.

Following a search and review of available tools the Triaster product "Process Navigator" was selected. This is powered by Microsoft Visio, and designed for non-process specialists, hence it was very simple and easy to learn to use.

Data was collected from the COMIT community, and other relevant external contacts. This was provided in the form of project procedures, form templates, or narrative explaining what the construction company currently does. Input was received from 25 companies, including most of the major UK contractors. This information was then collated to map out the generic “As Is” process for each of the ten.

The contributors then verified the “As Is” maps to ensure that they reflected the current situation accurately.

6.3 Stage 3: Map out the “To Be” processes

Once the “As Is” maps had been verified, areas for improvement were identified. These included:

- Activities where information was collected on paper at the point of activity
- Activities that could be fully automated if electronic data was collected at the point of activity
- Activities involving the delivery of paper information
- Activities involving the notification of personnel using traditional means (e.g. by telephone)

These areas were highlighted on the “As Is” maps and mobile IT, such as tablet PCs, hand-held computers, digital pens, barcoding, RFID tags, SMS messaging, GPRS/GSM and Wireless LAN, were proposed where their use would improve the overall process. The resulting changes in the process were then mapped out to form the “To Be” maps. For both the “As Is” and the “To Be” maps a colour coding for the deliverables was used: green – electronic file, orange – printed document (structured but handwritten input), red – handwritten document.

A narrative was written to accompany each set of maps. This provided an overview of the process, the issues that are present with the current approach, ideas for mobile solutions, details of the benefits that they bring and an assessment of how easy the solutions would be to implement. To ease the choice of the final four processes mobilisation “scores” were given. These provided a subjective assessment of how widely available relevant solutions are, the benefits to the end-user, the benefits to the organisation and the ease of implementation.

These “scores” were given at the top of each process narrative to provide information at a glance and help the COMIT community to decide which processes should be considered for the implementation of mobile IT on the demonstration projects. The scores were assessed as follows and then subsequently verified by the COMIT community in Stage 4.

An assessment of available solutions is made in accordance with how many solutions are available, their affordability, and are they in current use in the construction industry and/or will they require customisation to suit the particular process under consideration. The scores given were: Many, Several, and Few.

For any mobile solution to succeed it must deliver benefits that are directly apparent and of value to the end-user. This will encourage the adoption of the solution and hence help to deliver the organisational benefits. The scores given were: High, Medium, and Low.

User benefits will result in benefits to the organisation. In addition benefits will be derived through the collection of more accurate information, the reduction of information transfer time and the ability to search and utilise the electronic information subsequently. The scores given were: High, Medium, and Low.

The ease of implementation is assessed in accordance with whether the solutions are already in use on construction or similar industries, the readiness of the users to take up the technology and the current extent of electronic information in the process. Hence a judgement can be made on the length of time and the effort that would be involved in the implementation. The scores given were: Easy, Medium and Hard.

6.4 Stage 4: Select four processes

The COMIT community was presented with the “As Is” and “To Be” maps and the associated narratives. Once all of the processes had been reviewed, the construction companies were asked to vote for the top four processes they wished to see implemented on the demonstration projects. The four selected were:

- Monitoring health and safety on site
- Monitoring progress
- Site design problem resolution
- Maintenance inspections

The “As Is” map for each of the four processes will be developed to be project specific for the demonstration project and the proposed times and activity owners will be verified. Then once the demonstration projects have commenced the “To Be” maps will be verified and quantitative data will be collected to illustrate the process changes.

7 MONITORING CONSTRUCTION PROGRESS

Monitoring construction progress is detailed here to provide an example of the mapping activities carried out. By enhancing information flow between the different site processes and teams, it is easier to monitor, control and assess the project progress and hence integrate the on-site process (Moniem, 2000).

Site issues need to be resolved quickly and efficiently to avoid cost overruns and this often requires collaboration between on and off-site personnel (Miah et al., 1998). However, most project information is currently stored on paper, which is difficult to access and requires large storage space. A computerised information system can store vast amounts of data efficiently, and information can be located and viewed quickly through computerised searching and display (Liu, 1995).

Scott (1990) defined progress records as including personal diaries, minutes of progress meetings, daywork sheets, photographs and weekly progress reports. The main applications of these are:

- To confirm that work has been carried out
- To assess the progress of works
- To provide the main source of information detailing exactly what occurred

Initially, a project programme is drafted which provides a forecast of future works on a project. This is used to produce weekly progress sheets detailing the week's activities, the expected progress and a column to be completed for the actual progress.

Site engineers report back on a percentage complete (normally weekly) using visual inspection/numerical methods. The progress sheets are then compared with expected progress and the project programme is updated accordingly (see Figure 2).

Monitoring progress is vital to ensuring work is completed on time and that the project is progressing as planned. Penalties for the failure to complete on time will usually result in having to pay liquidated and ascertained damages (LADs), which could eliminate any potential profit that the contractor expected to make from the entire project.

Currently this process is heavily paper-based, and relies on the site engineers returning their progress sheets at the designated time. The information required is collected in many different locations on site and provided by several site engineers.

It is important that progress information is circulated to the entire project team including architect and consultants, as they may be able to provide ideas for getting the project back on track. The following issues were raised for this process:

- The process of reporting on progress is highly repetitive and laborious; therefore the quality of the information collected will suffer
- Progress reports often rely on the subjective assessment of percentage complete by the site engineer rather than an objective analysis
- The collation of data from several different sources is time-consuming and prone to data entry mistakes
- Formal reporting on progress only occurs periodically; therefore potential problems are often not foreseen before they occur
- Data transfer is often carried out manually between the progress reports which are produced in Microsoft Excel and the project programme produced using planning software

The following mobile IT solutions were proposed for the monitoring progress process and a two stage approach was recommended. The first stage will simply provide a form on a PDA electronic data capture at the point-of-activity. The second stage will integrate this further into the back-end systems.

A form could be created for use on the PDA to enable the site engineer to capture progress made whilst he is out on site. This could be distributed over the network such that each time the site engineer collects his/her PDA it is pre-loaded with the week's progress form.

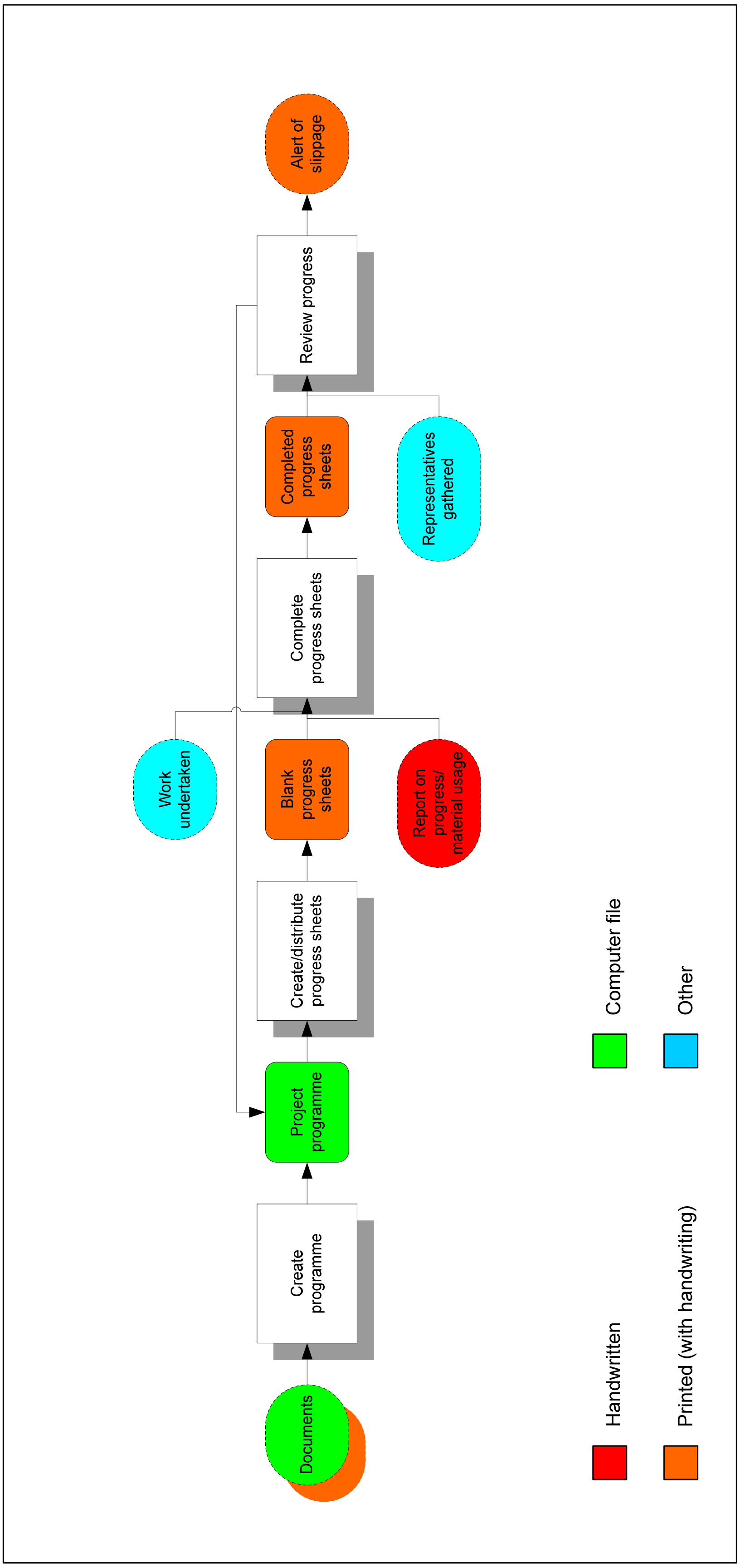

Figure 2: Monitoring Progress - "As Is" Map

Once the form is completed it could either be synchronised when the site engineer gets back to the site office or it could be synchronised via WLAN or GPRS whilst out in the field. Due to the nature of the data collected it is not thought necessary to provide progress data on more than a daily basis, hence synchronisation on return to the site office would be sufficient.

The data can then be fed into a progress database which would collate the data from each site engineer. This would enable the project progress report to be generated automatically.

The difficulty with producing the form for the PDA would be that the content of the form would change on a weekly basis according to the project programme. Greater benefits would be gained from enabling the forms to be automatically generated from the project programme. The data collected could then be fed straight back in to update the project programme.

Alternatively, relevant programme information could be distributed such that the site engineer can see each programme activity and simply select the completed tasks e.g. they could tick completed "drainage run from A to B" and automatically the materials usage is calculated. Linear activities could use GPS to show the distance completed but this may need to be supplemented by GPRS and Inertial Navigation data to obtain a desired accuracy of position. Potential areas for improvement to the generic "As Is" process were identified (see Table 1 and Figure 3).

Table 1: Areas for improvement

"As Is"	"To Be"
Planner copies and distributes blank progress sheets to site engineers 30 minutes each week	System distributes any revised/new blank progress sheets 0 minutes each week
Site engineer returns completed progress sheets to the planner 30 minutes each week	Completed progress sheets are synchronised with the central progress database 3 minutes each week
Slippages are alerted to all of the project team 1 hour each month	Slippages are alerted automatically via SMS 0 minutes each month
Planner produces (monthly) progress report 3 hours each month	System automatically generates (monthly) progress report 0 hours each month

The times given above are indicative only and will be verified on the demonstration projects. Using these times an overall time saving of at least 1 day each month of the planner's time is achieved by using mobile IT. However, there are other benefits that are more difficult to map and measure.

Capturing progress information directly in the field provides contemporaneous information, eliminating errors typing up information from handwritten notes or from memory. It also allows the site engineer to spend more time out on site undertaking work that enables the project to be completed on time and on budget.

Providing an easy way for site engineers to capture the information may lead to the information being collected on a more regular basis. This increased feedback could help in the early identification and troubleshooting of many problems, thus avoiding unnecessary escalation of issues on site.

Slippage alerts could be generated automatically and emailed to the appropriate person who can initiate remedial measures.

The correlation of the progress information is automated, monthly progress reports can be generated at the touch of a button, and the information can be manipulated and displayed easily. Many potential error-prone manual paper processes are skipped, saving worker time and resources.

The project team will have access to more timely and accurate programme information and will be able to move from trying to understand what has happened to figuring out what to do about it.

An assessment was also made for the ease of implementation of a mobile IT system for this process. The provision of a PDA form for the collection of progress information is relatively simple and there are many packages available that can be used to create the form. Initially this form could have the same appearance as the current paper forms thus providing the user with a familiar interface.

Primavera, a major provider of project management software offer a solution called Mobile Manager, which provides programme information through a PDA. Although this alleviates the issue of linking progress information back into the project programme it provides a more complex interface which may be less readily understood and hence used. It also relies on Primavera being used for creating the project programme, which may not always be the case.

The mobilisation “scores” given for this process were:

- Available solutions: Several
- User benefits: Medium
- Organisational benefits: High
- Ease of implementation: Medium

The COMIT community ranked this process joint first alongside monitoring health and safety on site.

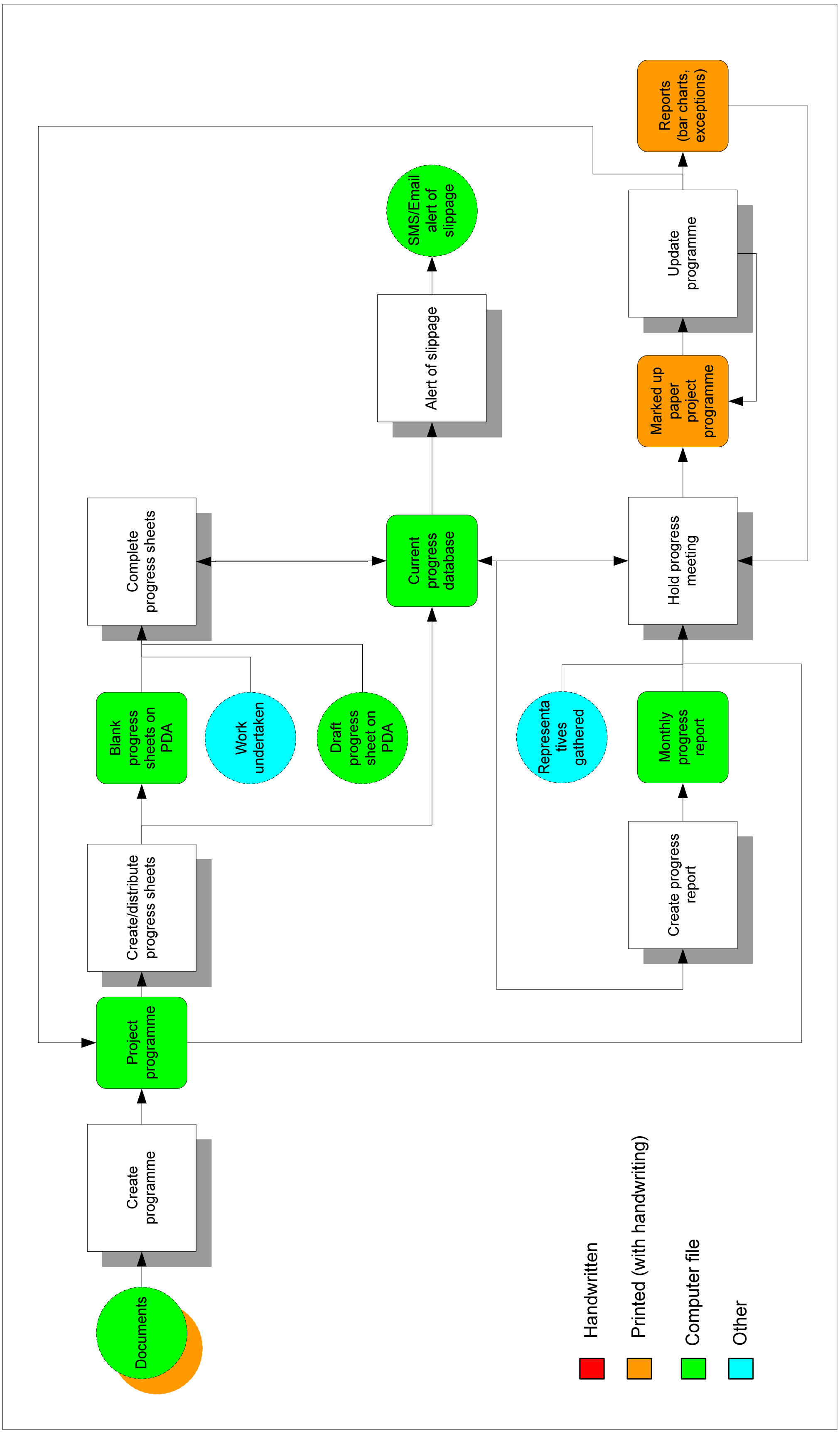

Figure 3: Monitoring Progress "To Be" Map

8 MOBILISATION PLAN

The mapping approach that was followed enabled the identification of common deliverables and personnel across the ten processes e.g. the Project Plan is utilised in the processes for Monitoring progress, Task allocation, Goods received notes, Quality inspections and site diaries. This provides a guide to which processes should be "mobilised" in which order, although the benefits achievable should also be taken into account.

Figure 4 illustrates how closely related the information requirements of each process are.

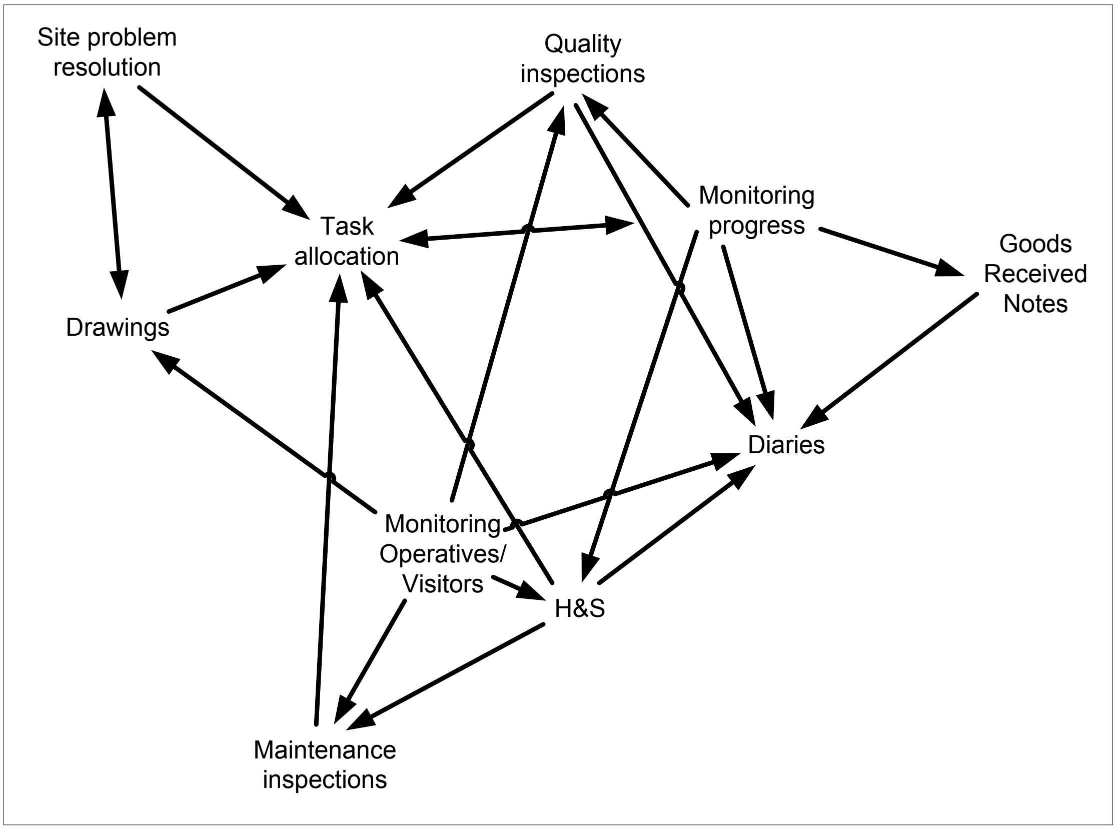

Figure 4: Process linkages

It is suggested that justifying the business case for one process can be enhanced by choosing a process that utilises information common to other processes. Once the first process has been "mobilised" some of the electronic data required to mobilise a subsequent process is already provided. Additionally, the equipment required is already available, the users may be the same and hence the barrier to acceptance of a new solution is lowered and also the training required.

9 NEXT STEPS

Mobile IT solutions are currently being developed for the four processes that have been selected for implementation on the demonstration projects. Training and implementation will begin in Autumn 2004 and the projects will be monitored until July 2005.

Quantitative data will be collected to verify the costs to the contractor and the benefits that mobile IT brings. This data will be collated and compared across the four projects to demonstrate real-life business cases for mobile IT. In addition, human factors and cultural barriers will be analysed and reported on to provide the construction industry with comprehensive guidance in order to aid future development and implementation of appropriate mobile IT solutions.

10 CONCLUSIONS

Mapping the “As Is” processes provided the research team with a sound basis on which to determine the “To Be” processes. Mapping each activity and deliverable and highlighting the areas for improvement enabled ideas for the “To Be” process to be developed, often resulting in unforeseen improvements. The knock-on effects of implementing a mobile IT solution were also much more clearly identifiable.

One of the difficulties with illustrating the changes through the process maps was that the “To Be” map often appeared more complicated than the original “As Is” map. This was due to the use of a central database which created feedback loops on the maps, and automated activities still being included on the maps. It would be useful to illustrate the changes in activities for each individual participant so they can see graphically a real reduction in activities and the time taken to complete them.

Although the maps provide an indication of the improvements that could be made there is no real substitute for the information that can be gathered from a pilot project and the demonstration projects will enable us to improve on the process maps by providing a real view of the “To Be” process and the associated quantitative information.

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APPENDIX 4: PAPER 4

FULL REFERENCE

Bowden, S.L., Dorr, A., Thorpe, A. and Anumba, C.J. (in press). Mobile IT support for construction process improvement, *Automation in Construction*.

ABSTRACT

This paper brings together the visions for information and communications technologies (ICT) in construction and the changing requirements of the construction industry. Drawing on case studies, previous research and future scenarios outlined by research road mapping projects, it illustrates how the areas identified as having potential for improvement can be addressed through the use of mobile IT. This vision is then developed into a scenario for communicating to industry professionals the construction site of the future. Their feedback on this scenario is used to assess the viability of the research propositions within mainstream construction. Finally, the paper examines the implications for the construction industry should the vision for the future be adopted; the potential for new islands of automation; the effects on our human resources; and the potential impact on knowledge management initiatives.

1 INTRODUCTION

Global economic competition has compelled many organisations to explore all possible options for improving the delivery of their products or services (Drucker, 1994). This trend has also become apparent in the construction industry, with clients expecting a better service and projects that meet their requirements more closely. This has challenged the industry to become more efficient, integrated and more attractive, both in the eyes of society and its potential workforce. In response, government, industry or research-led construction change initiatives have emerged in most developed countries (2002).

In parallel with, and to serve, these initiatives there has been a concerted effort, within the research and academic sector, to explore and implement existing and emerging information technologies that facilitate the improvements required to modernise the construction industry.

Progress has been driven by a combination of technology push and demand pull. Several authors have argued that construction typically lags behind other industries in its use of IT and hence one could deduce that the primary driver is technology push. However, more recently many would argue that the reason the construction industry has been slow to adopt new technologies is that they have not yet been developed to suit the needs of the industry, hence there is a strong demand pull which is yet to be satisfied. For example, it is relatively easy to implement new technologies in a manufacturing production line where it is a clean, stable environment and the work travels to the worker. However, on a construction site the worker has to travel to the work and take the technology with him/her and is subject to the natural elements.

The continuing development of affordable mobile technologies such as handheld computers, SmartPhones and Tablet PCs alongside the latest generation communications infrastructure (3G, WLAN and GPRS) could provide the 'last mile'; connection to the point-of activity and hence provide the missing link to help address the ongoing drive for process improvement and re-valuing construction.

2 WHAT NEEDS TO CHANGE?

The construction change initiatives have all set out a vision of where the industry should head to. Some have set specific targets; for example, Rethinking Construction (Egan, 1998) and US National Construction Goals (Shaw, 1996). Others have simply defined the way they want to work in broader terms, for example, through integrating the supply chain, industrialisation of the building process and increased technological innovation and use of ICT (Building Policy Task Force, 2000, ISR, 1999, Kohvakka *et al.*, 2001). Sought after improvements, common to most of the initiatives, include:

- reduction in construction time;
- reduction in capital cost of construction;
- reduction in defects;
- reduction in accidents;
- increase in predictability;
- reduction in waste;

- increase in productivity;
- reduction in operation and maintenance costs.

3 ICT ROAD MAPPING INITIATIVES

In recent years there have been several road mapping projects that have set out to determine how ICT could influence the future of the construction industry. These visions have been formulated taking account of industrial requirements and the opportunities offered by evolving ICT. This section provides an overview of several of these initiatives which made reference to the application of mobile technologies.

3.1 CIB W78

Information technology has become a major research topic in the construction industry for the last twenty to thirty years. In 1983, the International Council for Research and Innovation in Building and Construction, also known as the CIB, formed the W78 Working Commission focusing initially on computer aided design. This has now been broadened to IT in Construction. The W78 work programme commissioned three related activities: a review of W78 work to date (Amor & Betts, 2001); a short to medium term vision for construction IT (Sarshar *et al.*, 2000); and a longer term research agenda examining the future IT support required for construction projects (Froese *et al.*, 2001).

The three main themes covered in W78 conferences have been: computer-integrated construction; IT supported process improvement; and decision support knowledge based systems and artificial intelligence. The conference programmes in 2002 and 2003 included papers on the use of mobile IT.

Sarshar et al (2000) conducted a literature review supplemented by academic and industry workshops. This resulted in the formulation of seven themes describing their vision for construction IT 2005 -2010:

- model driven, as opposed to document driven, information management on projects;
- life cycle thinking and seamless transition of information and processes between life cycle phases;
- use of past project knowledge (/information) in new developments;
- dramatic changes in procurement philosophies, as a result of the internet;
- improved communications at all life cycle phases, through visualisation;
- increased opportunities for simulation and what-if analysis;
- increased capabilities for change management and process improvement.

These themes were then used to shape a scenario around the phases of a construction lifecycle; conception of need; tendering and team selection; design and briefing; construction and facilities management. Example uses of mobile technologies highlighted were:

- *Buildability*- Staff can use 3rd generation mobile phones and visualisation to zoom into different areas of buildings and check how to assemble components;
- *Material delivery and tracking*- Auto-ID tags will be a prominent technology for tracking material movement;
- *Progress monitoring and programming*- As construction progresses, staff update the programming information. Any problems or changes are recorded on the model. This will allow virtual progress monitoring;
- *As-built information*- If the design is changed, due to last minute considerations, as-built information can be captured and handed over to the client.

Froese's (2001) survey of academia and industry concluded that the overriding role of IT will be to provide ready access to all information at all times, and to support much richer forms of communication and information sharing. The respondents indicated that they expected that the types of computers they would be using in 2020 would be predominantly wirelessly networked and there would be a definite shift towards laptop and palmtop computing alongside embedded computers in tools, vehicles etc. An increase in the use of voice input and output was expected, with the accompanying demise of the use of paper printouts.

3.2 EU's Framework Programme

The European Commission has also funded several road mapping activities under their fifth and sixth framework programmes within Information Society Technologies (IST). The ICCI (Innovation co-ordination, transfer and deployment through networked Co-operation in the Construction Industry) project brought together the results from six IST projects for the construction industry. Future needs, research and technological developments, and plans for ICT in construction were identified from a literature review and enquiry among the ICCI partners (Nederveen *et al.*, 2004). The themes for the future were summarised as:

- value orientation and sustainability;
- virtual organisations;
- life-cycle integration;
- reuse of information and knowledge;
- IFC-based or model-based ICT;
- advanced Internet technologies (based on XML, SOAP etc);
- legal and contractual aspects of ICT in construction;
- human and organisational aspects of ICT in construction.

Ambient access (technologies enabling communication and information access and sharing via mobile devices on the same level as fixed devices) was identified as an ICT enabler to achieve the future vision.

The ROADCON (Strategic Roadmap towards Knowledge-Driven Sustainable Construction) project's aim was to develop a vision for agile, model-based / knowledge driven construction and to prepare a roadmap towards achieving that vision (Hannus *et al.*, 2003). The vision for future ICT in construction was defined as:

"Construction sector is driven by total product life performance and supported by knowledge-intensive and model based ICT enabling holistic support and decision making throughout the various business processes and the whole product life cycle by all stakeholders."

Within the ROADCON vision the areas of particular relevance are: Ambient access; and Digital site. The detailed level roadmaps for these are shown in Figures 1 and 2.

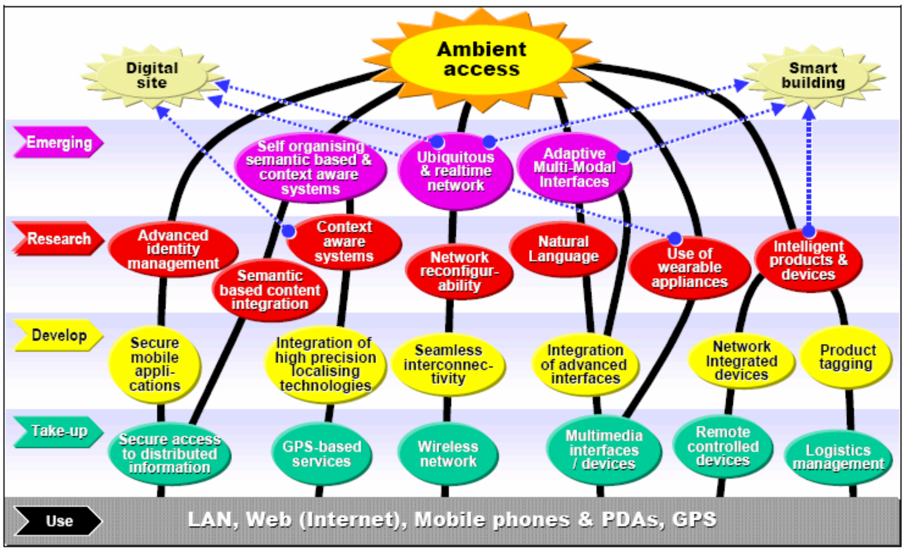

Figure 1: Roadmap for ambient access (Hannus *et al.*, 2003)

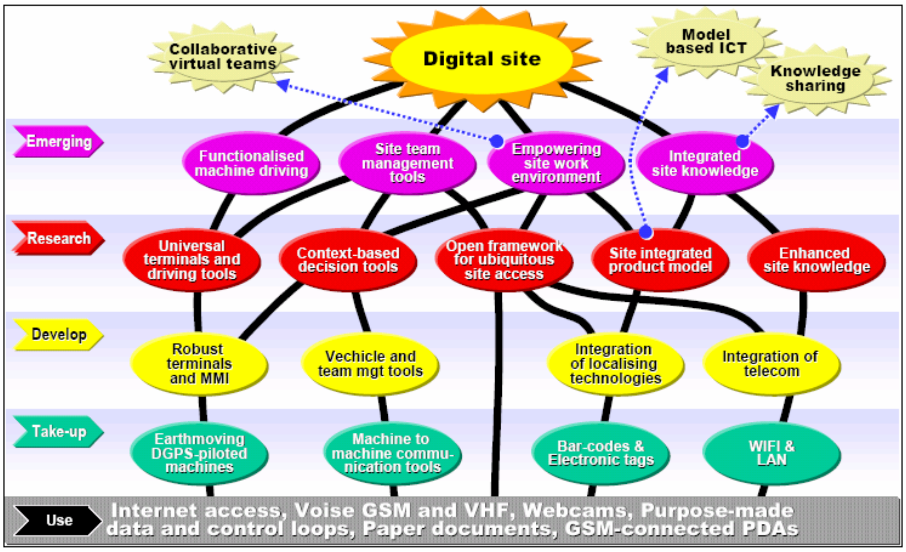

Figure 2: Roadmap for digital site (Hannus *et al.*, 2003)

3.3 FIATECH

FIATECH, a non-profit consortium in the USA, has developed the Capital Projects Technology Roadmap which is a cooperative effort of associations, consortia, government agencies, and industry, working together to accelerate the deployment of emerging and new technologies that will revolutionize the capabilities of the capital projects industry. The roadmap is illustrated in Figure 3; of particular interest are the "Intelligent and Automated Construction Job Site" and the "Integrated Automated Procurement and Supply Network" which incorporates the following visions of the future:

- location and status of all materials, equipment, personnel, and other resources will be continuously tracked on site, thus enabling a "pull" environment where needed resources are delivered on demand;
- automation of construction processes will augment manual labour for hazardous and labour-intensive tasks such as welding and high-steel work;
- construction job sites will be wirelessly networked with sensors and communications technologies that enable technology and knowledge-enabled construction workers to perform their jobs quickly and correctly;
- asset Lifecycle Information Systems will continuously monitor the job site for compliance with cost, schedule, material placement and quality, technical performance, and safety. This will provide downstream facility operations with much better documentation about the history and current state of the facility;
- the site monitoring and tracking system will compare daily construction progress against the plan and coordinate the continuous flow of materials and assemblies to the point of need.; reducing the need for on-site storage;
- the site asset tracking and control system will enable workers to instantly locate the resources they need and get them delivered for immediate use.

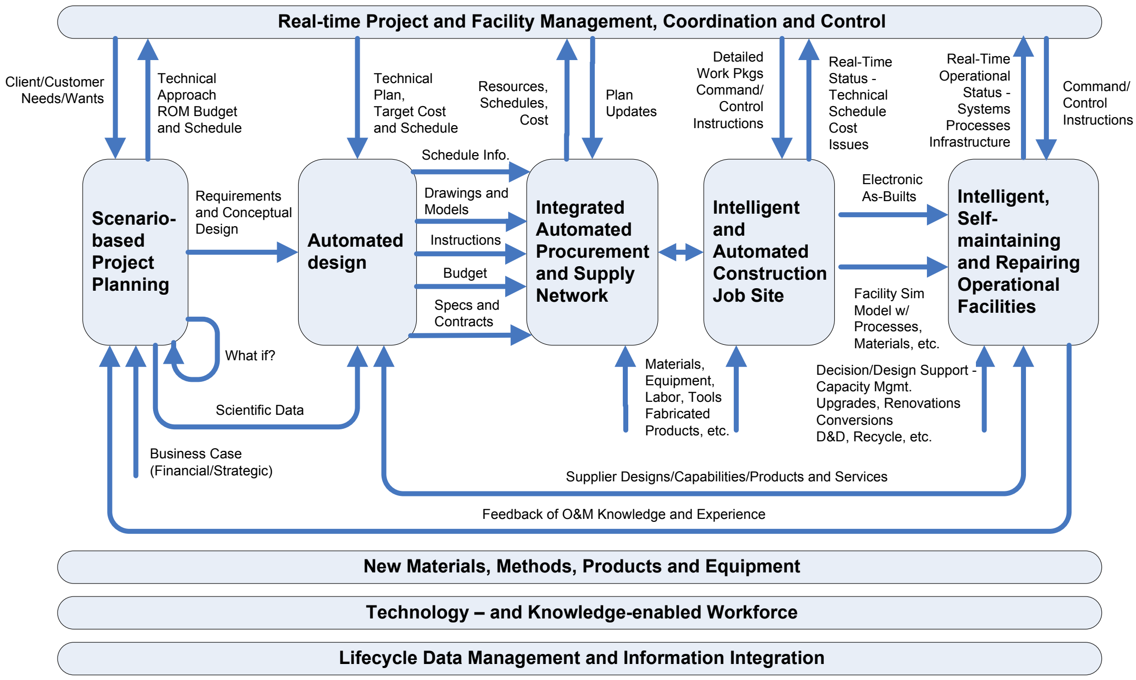

Figure 3: The Capital Projects Technology Roadmap (FIATECH, 2004b)

3.4 Summary

The road mapping initiatives detailed above have addressed the future vision of ICT in construction at very different levels of granularity. Like the construction change initiatives some have focused on defining the macro-level new ways of working that will be adopted (e.g. Sarshar's vision for construction IT) and others have focused on the micro-level of how the actual technologies will be applied (e.g. FIATECH). For the purposes of this paper these visions will be incorporated into a vision of mobile IT use in the construction industry.

4 THE ROLE OF MOBILE IT

With the introduction of laptops into the work environment as a substitute for personal computers, the potential of the mobile worker became evident (Faigen & Fridman, 2004). The development of affordable mobile technologies has enabled their deployment in all sectors of industry and commerce. From bar codes on weekly shopping to a hospital consultants recalling a patient's records using a PDA; the ability to capture, store and re-use information by a mobile user is now commonplace (Dhawan, 1996, Escofet, 2004). The recent advances in technology have increased the performance and reduced the price of many mobile computing devices, resulting in fresh interest in their potential application in the construction process.

This section brings together the visions for ICT in construction and the change requirements of the construction industry. Drawing on case studies conducted as part of the COMIT project (Bowden *et al.*, 2005), previous research work in this area and the future scenarios outlined above, it illustrates how each of these areas for improvement can be addressed through the use of mobile IT, both in the present and the future.

4.1 Reduction in construction time and capital cost of construction

Mobile technologies can facilitate a reduction in construction time and capital cost. Generic benefits of the provision of mobile technologies to point of activity workers include:

- elimination of rewriting/retyping;
- reduction in travel time to retrieve information;
- reduction in travel time to view point-of-activity.

Additional time and cost savings are illustrated in each of the improvements facilitated by mobile technologies outlined below.

4.2 Reduction in operation and maintenance costs

There are two areas in which mobile technologies can facilitate a reduction in operation and maintenance costs; increasing the efficiency of maintenance personnel and the collection and provision of information throughout the life-cycle of a building or structure.

Network Rail's London, North East and East Anglia Region are using a PDA, GPS and GIS system to undertake earthworks inspections; examining the integrity of their embankments and cuttings. Network Rail now receives data from the examinations team on a weekly basis rather than at the end of a four month inspection. This enables Network Rail to proactively plan their maintenance workload accordingly. Data collected in the GIS can easily be ranked by condition enabling the identification of all 'poor' earthworks, including their location (automatically recorded by the GPS). A maintenance team can then be instructed to rectify groups of faults in a single pass. Network Rail achieved payback for the solution within one year (Bowden, 2004).

Rosser and Russell have implemented a GPRS connected PDA solution for delivering work orders and collecting progress information from their maintenance engineers. There has been a substantial reduction in administration required to manage their maintenance operation. The payback period for this solution is estimated as 10 months (Gooding & Bowden, 2004a).

Biwater implemented a fleet management system utilizing GPS trackers. This has enabled them to monitor in real-time the location of their maintenance crews. Response times have reduced as the nearest free crew to the incident can be located and instructed. The improved logistics has reduced mileage, hence reducing the fuel costs (and also maintenance costs) of the fleet. Biwater estimate payback within seven months (Gooding & Bowden, 2004b).

There is also the opportunity to further enhance the information provided to maintenance crews, by providing location based services such as the nearest approved supplier of the required replacement part.

The second area of life-cycle information flow has been highlighted in the construction ICT road mapping initiatives. Gallaher et al (2004) estimates the cost of inadequate interoperability in the U.S. capital facilities industry conservatively to be $15.8 billion per year, the majority of this, $9.1bn, is in operation and maintenance costs. An inordinate amount of time is spent locating and verifying specific facility and project information from previous activities. For example, as-built drawings (from both construction and maintenance operations) are not routinely provided and the corresponding record drawings are not updated. The cost of time spent ensuring that the information accurately represents what is set in place is estimated to be $4.8 billion.

Mobile technologies provide the opportunity to create and store as-built information as the project is constructed and then to provide and store information for the ongoing maintenance activities. Chapman (2000) proposes the following solution. Each component of the structure is tagged and as the structure is built the position and orientation of each component is fed back into the central project model. When the building is handed over to the owner, he also receives access to the central project model. This will contain not only details of the components but also when and if any of them have to be inspected. Routine maintenance of the building is scheduled automatically and the maintenance engineer then simply has to go to the item to be inspected, scan the tag, and all of the information he/she requires will be delivered straight to the point-of-activity.

Embedded mobile technologies can take this a step further. Sensors that detect when a pre-determined state has been reached (e.g. a strain or temperature gauge) can send an alert to the owner to inform him/her of maintenance required (Hannus *et al.*, 2003). This could prevent components reaching failure and hence avoid replacement costs.

4.3 Reduction in defects

Several of the national change initiatives challenge the industry to aim towards zero defects on handover. For example although Egan (Egan, 1998) set the target for UK construction as a 20% annual reduction in the number of defects on handover. He also suggested that there is much evidence to suggest that the goal of zero defects is achievable across construction within five years and stated that some UK clients and US construction firms already regularly achieve zero defects on handover.

The snagging process is an obvious application for mobile technologies as it can be highly repetitive and is predominantly list-based. Mace has used a PDA solution and Taylor Woodrow piloted a digital pen and paper solution. Both solutions provided the ability to collect the data electronically at source in a uniform format, which was then stored in a central database. The database can be searched for trends; reoccurring defects, re-offending sub-contractors and delays in rectifying defects. These trends can then be addressed proactively. An additional benefit of having a central system for defect management is that the costs of rectifying snags can begin to be understood and hence a more proactive approach to managing quality throughout the construction process should be adopted to avoid these costs (Sommerville *et al.*, 2004).

Research in Australia showed that showed that 65% of contractor-rework is attributed to insufficient, inappropriate or conflicting information (Newton, 1998). Stent Foundations Ltd. developed a Tablet PC system connected to a central database via a wireless LAN to facilitate pile construction. They found that defects have been reduced because site staff have access to more accurate and up to date information, and their understanding of the piling process better and ensures more consistent adherence to procedures. Analyses from the pilot project indicate a 75% reduction in the cost of remedial work. Based on a company turnover of £50M this equates to a potential saving of £385,000 per annum if the system were to be used throughout the company (Gooding & Bowden, 2004c).

Automated construction through the use of GPS assisted machinery offers further quality improvements. Accuracies of a few millimetres are possible. The primary applications to date have been in earthmoving, profiling and surfacing equipment (Peyret *et al.*, 2000). Using GPS eliminates one stage of potential human inaccuracy, the setting out process, where wooden stakes and string are used to indicate the work to be undertaken. Regular users profess that productivity and quality are increased, and rework is reduced (Jonasson *et al.*, 2002).

4.4 Reduction in accidents

Construction is recognised internationally as one of the most hazardous industries to work in; in the UK the fatal injury rate of 3.6 per 100,000 workers, equating to 70 people, compares unfavourably with the all industry average of 0.81 (HSE, 2004); 30% of all worker fatalities occurred in construction. However, in recent years, health and safety has become more widely recognised as a business performance issue on a par with delivering to time, cost and quality (Myers, 2003).

Measuring accident frequency is recognised as a rather outdated reactive technique assuming that accidents are the measure of safety performance (Ahmed *et al.*, 2001). The construction industry is now moving towards a proactive rather than a reactive approach by conducting regular health and safety audits and inspections. There are several examples of mobile IT tools that have been developed to undertake safety inspections (Becker *et al.*, 2001, Hawkins, 2002a, KOL, 2003, McKernan, 2001).

Skanska Tekra Oy, the civil engineering division of Skanska in Finland, are using an SMS/WAP and MMM based system which allows data to be collected electronically using the supervisor's phone. It then sends problem notifications to the sub-contractors who can respond via SMS when the problem is rectified. Corrective actions that previously took days to complete are now done in a few hours, and accidents have decreased since the implementation of the system.

The data collected is all stored on a central database enabling the identification of trends to be automated. Persistent non-compliances can be highlighted and a more proactive approach to eliminating their reoccurrence can be put in place, such as training through toolbox talks, new methods of construction or other preventative measures e.g. placing warning signs and barriers around overhead electricity cables. In addition, sub-contractors who are consistently causing safety issues and/or are slow in resolving them can be highlighted and dealt with accordingly.

The mobile system replicates the 'MVR' safety method for civil engineering developed by the Finnish Institute of Occupational Health which has been adopted by most of the large contractors in Finland. By having a single tool, comparison across sites and even across the industry is possible facilitating further improvement and a reduction in the number of accidents.

The "Accident Triangle" illustrates that fatal injuries are just the tip of the iceberg (Figure 4). Theory states that if you reduce the number of near misses, this in turn will reduce the number of fatalities (Heinrich *et al.*, 1980). The records of near misses are currently very poor. This could be due to the sheer number that occurs and hence the amount of paperwork involved in recording them.

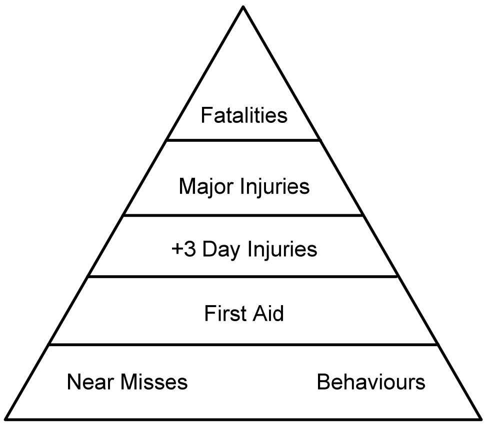

Figure 4: The accident triangle (Walker, 1997b)

Mobile technologies could provide a mechanism that enables workers to report near misses more easily at the point of activity, which in turn would increase the number of near misses reported. This electronic data could be automatically analysed and highlight those areas in need of improvement.

Falls from height are the most common cause of fatal injury (Kisner & Fosbroke, 1994). A tablet PC audit tool was developed to accompany the OSHA Fall-Safe programme in the USA (Becker *et al.*, 2001). The work concluded that the conduct of an audit and the reports generated contribute to improvements in contractor control of fall hazards.

After falls from height, the next most common kind of fatal injury is being struck by a moving vehicle (accounting for 10 fatalities in the UK in 2003/2004). Work is currently being conducted in the Oil and Gas industry on the application of virtual exclusion zones for oil platform cranes. Using a camera mounted on the crane boom, image processing to identify and distinguish people from containers and tracking algorithms to compute position of personnel in the area it is possible to provide an audible alert both the crane driver and the personnel that they entering the danger zone. The location of personnel can be clearly provided to driver on an in-cab display whilst ensuring minimum distraction. Although, vehicles provide audible alerts currently when they are reversing this warning is not directed specifically to the person in danger and can be ignored as background noise. This virtual exclusion or information zone could be utilised in the construction industry providing warning around machinery such as piling rigs or cranes and to provide information when entering areas with specific safety requirements.

A step further along the line towards improving health and safety on site is the possibility of automated construction, eliminating the need for personnel to be in danger areas. An example application is presented by Oloufa et al (2003). The Fujita tele-earthwork system was used in Japan to work in the shadow of a live volcano; Mount Fugen. All of the construction equipment at the site operates without on-board drivers. The vibrating roller moves autonomously, aided by Global Positioning System (GPS). Further enhancements to the remote controlled system are proposed providing real-time tracking of construction equipment utilising the GPS and wireless communications to avoid collisions.

4.5 Reduction in waste

Construction and demolition (C&D) debris constitutes the waste generated during construction, renovation, and demolition projects. C&D waste commonly includes building materials and products such as concrete, asphalt, wood, glass, brick, metal, gypsum wallboard, roofing, insulation, doors, windows and frames, flooring, and furniture.

The U. S. Environmental Protection Agency (EPA) estimates that approximately 136 million tons of building-related C&D debris were generated in 1996—the majority from demolition (48 percent) and renovation (44 percent). New construction generated only 8 percent of building related C&D debris (EPA, 2002).

In Europe, where there is much greater pressure on landfills due to high population densities, C&D waste has been named a "priority waste stream" by the European community and is being targeted for reduction. In Germany, the government reached a voluntary agreement with the construction industry in 1996 to reduce the amount of C&D waste going to landfills by 50 percent from 1995 levels by 2005. The Swedish Environmental Protection Agency has also called for a 50 percent reduction in C&D landfill within 10 years (Fishbein, 1998). The first step in understanding and reducing wastage on site is to know what materials and equipment have been delivered. Several construction suppliers are currently considering or piloting mobile IT solutions to facilitate their goods delivery process, providing electronic goods received notes (GRNs) and proof of delivery. A commonly held view is that the weakest point of the supply chain in the construction industry is the site; paper gets delivered and then lost. It may not get filed properly and the people onsite have no real awareness of how all the documents in the supply chain are linked. Lost GRNs is a huge problem for both the contractor and the supplier. One supplier stated that out of 4.5 million tickets issued each year contractors asked them to replace 300,000 GRNs. A contractor stated that on a £45million project £133,000 of invoices was being queried on any one day (Bowden & Anderson, 2004).

Tracking materials and equipment once they are on site through the use of barcoding and RFID tag technologies has been the subject of much research (Chen *et al.*, 2002, Hawkins, 2002b, Jaselskis & El-Misalami, 2003, Marsh, 2000, Ruck, 2001, Song *et al.*, 2004). The benefits achieved in relation to waste reduction include:

- faster location of materials/equipment;
- certainty that only the correct materials are used, reducing costs associated with damaged items;
- reduction in lost or stolen items;
- easier maintenance of a materials tracking database.

CPIC (Centre for Performance Improvement in Construction) has developed a toolkit for measuring performance on site; CALIBRE 2000. Wastage in time, materials and energy are collected by construction "observers" using a PDA device, which is then synchronised with a central database. The PDA enables information to be collected in real-time and it is then available for analysis by the site team the next day. Chen et al (2002) suggest the use of bar-codes to facilitate a crew-based incentive reward program (IRP). The workers are rewarded according to the amounts and values of materials they saved from their operations. This resulted in a 10% saving of material wastage.

In both of these examples the drawback is that collection of the data still requires manual intervention. Li et al (2005) take the next step by integrating GPS and GIS to propose an automated real-time data collection solution to manage deliveries of materials to site. In the future it will be possible technically to utilise these technologies at a micro-level on site to automatically pin-point the location of materials and equipment on site and process that location accordingly e.g. if the location of a cladding panel is recognised as being in a skip then the wastage work-flow will be instigated.

These technologies can also aid efforts to implement logistics initiatives within the construction industry. With reliable real time supply chain visibility, just-in-time delivery of materials and equipment is possible (FIATECH, 2004a, Sarshar et al., 2000). This reduces the possibility of damage to materials from ingress of weather and movement of people, plant and equipment within temporary storage facilities.

As stated above, the majority of C&D waste is generated during demolition and renovation. RFID tagging provides the capability of attaching information permanently to building components, which in turn offers the opportunity to provide future owners with information about the make-up of each component. Items can then be easily identified for recycling or reuse; even those items that cannot currently be recycled may be recyclable in the future. This would eliminate some of the prohibitive costs associated with identifying and sorting materials, making recycling a more viable option.

4.5 Increase in productivity

Productivity is defined as the ratio of the amount of work produced to the resources used in its production. Productivity is increased if it takes fewer resources to do the same amount of work, or the same number of resources can achieve more. The drive for improved productivity in the construction industry has come with the recognition that productivity is inextricably linked to international competitiveness (Cattell *et al.*, 2004, ISR, 1999) and that the construction industry has not kept pace with productivity improvements gained in other industries (Teicholz, 2004). Several of the national construction change initiatives promote the use of information technology as a tool to increase productivity, through automating tasks and enhancing collaboration (ISR, 1999).

Task automation provides the following productivity enhancements:

- delivery of required information e.g. method statements;
- production of reports e.g. daily progress reports;
- alerts e.g. notification of safety hazard;
- data collation, reduces number of administration staff required.

One area where significant losses in productivity can occur is downtime on site due to unforeseen problems (De la Garza and Howitt, 1998). The opportunity for mobile technologies to provide immediate access, from the point-of-activity, to the personnel which may be able to resolve the problem has been an ongoing subject of research (Liu, 1995, Magdic *et al.*, 2004). Initial solutions focused on the digital hard hat, however, the costs involved, the size of the equipment required at the time and the acceptability of the solution prevented its mainstream use.

Mobile technologies have now developed to a stage where consumer hardware and software provide many of the capabilities required; live two-way voice, video and data transfer. Stent Foundations Limited is currently piloting a solution that enables the site team to communicate directly with the office-based team to resolve an issue on site. This eliminates the downtime waiting for someone to travel to site to view the problem, and provides direct communication rather than through the traditional hierarchical route therefore eliminating misunderstanding of the problem and the delivery of unsuitable solutions.

Another area that is leading to improved productivity is Lean Construction. This is a production management-based approach to project delivery (Howell, 1999); one element of this approach is the Last Planner system of production control. The "Last Planner" is the person or group which decides what physical, specific work will be done tomorrow (Ballard & Howell, 1994). The Last Planner system has been set up to facilitate this method of planning and its toolset includes:

- collaborative programming;
- look-ahead meeting;
- weekly work plan meeting.

The premise is that better planning improves productivity by reducing delays, getting the work done in the best constructability sequence, matching manpower to available work, and coordinating multiple interdependent activities (Ballard, 2000). One of the criticisms of the system is that it requires too much paperwork (CIRIA, 2004).

It is proposed that mobile technologies can help to further enhance this system by eliminating the paperwork required to maintain the system. Pearce Group Ltd. is currently trialling a mobile system that facilitates the Last Planner process, maintaining and enhancing the collaboration and face to face aspects whilst removing the needless data re-entry and providing up to the minute information. The results of this pilot will be published in autumn 2005.

4.6 Increase in predictability

The construction industry is often criticized for delivering projects late and over budget (Bourn, 2001). There are a multitude of reasons for this including culture, procurement methods and communication issues. One area in which mobile technologies can help is in providing accurate real-time progress and cost information as the project progresses.

In the sections above it can be seen that increased communication from the point-of-activity back to the rest of the project team is possible and in some cases already being achieved. Mobile applications already exist for timesheet, plant utilisation, materials management and progress reporting. It should now be possible to compare the planned programme or budget with the actual progress or costs collected and use this information to inform later project stages and/or future projects.

5 THE FUTURE CONSTRUCTION SITE

The previous section synthesised the research undertaken to date for mobile computing applications and illustrated how these technologies could support the improvements sought after by the construction industry. However, a reason often given by industry practitioners for the low uptake of construction IT innovations is the mismatch between some of the systems being developed by researchers and the needs of the construction industry. Researchers tend to concentrate more on what is academically exciting and technologically challenging instead of addressing real industry problems (Anumba, 1998). To assess whether the research proposals are valid and address industry needs a method for communicating the possibilities to non-IT construction professionals was required. It was determined that a simple scenario should be developed and put forward for review by a sample of construction industry practitioners. Their feedback was then collated and is discussed below.

The scenario assumed that the traditional roles and responsibilities of construction staff remained the same, however, if and when the scenario becomes common practice these roles and responsibilities may change. The actors in the scenario are shown below in Table 1.

Table 1: Scenario actors

Name	Job Title	Company
Joe	Foreman	BuildIT contractors
Sophie	Planner	BuildIT contractors
Phil	Site Engineer	BuildIT contractors
Sue	Health and Safety Inspector	BuildIT contractors
Fred	Ganger	DrainIT subcontractors
Steve	Operative	DrainIT subcontractors
Peter and Jane	Drainage Designers	DesignIT consultants

5.1 Future construction site scenario

Joe arrives on site at 8am, as he enters the site he is automatically registered and receives confirmation of his tasks for the day. He looks at his list of tasks on his SmartPhone and notes his first task is to supervise the excavation of a manhole. He selects the task and downloads the relevant information; location map, method statement, permit to dig and risk assessment. Joe then heads to the manhole location and meets Fred and his gang there who have also been notified of their tasks for the day on their phones.

Once at the location, he unfolds his e-paper and views the location map; this is automatically orientated using his position and shows him where the buried services are (pulled down from the National Services database). He notes that there is an electricity cable close to the location and checks that this has also been picked up on the excavator's system. He is still new to using the system and does not trust it yet.

He ensures that the gang are happy with the method statement and aware of the risks involved. They all then select Y on their phones to acknowledge this. An alert comes through on Joe’s SmartPhone advising him that one of Fred’s gang, Steve, has not yet received his safety induction. He ensures Steve is wearing the correct PPE and calls Sue to ask her to provide Steve with an induction.

Sue is currently at the other end of the site, so she decides to provide the induction to Steve using the video-conference phone facilities. She notes his location and advises him of specific hazards in the area along with the general site safety instructions. Once the induction is completed, she asks Steve to acknowledge he has been inducted by pressing Y on his phone.

The excavation begins; the excavator driver is provided with location information to ensure the hole is dug to the correct dimensions. The excavation is completed. Fred selects the sub-task on his phone and presses Y to signify completion. Phil receives an alert on his phone to let him know that the excavation is ready for inspection. He downloads the final dimensions from the excavator to ensure these are correct and then heads out to check that the excavated base is firm and stable prior to concreting.

Joe receives an alert as well and looks up the materials that are now required to complete the manhole. All of the materials are in the stores except for the step-irons. Joe checks the status of these and sees that although they ran out yesterday, the supplier was automatically alerted to deliver some more to meet the programme and they are due for delivery later that afternoon. Joe selects “Deliver” on his SmartPhone and an alert is sent to the stores asking them to deliver the materials to the excavation location.

Sue is conducting the health and safety inspection of the site. She comes across the manhole work and sees that the excavation has not been fenced off and there is no-one around. She says “excavation” and a menu of applicable hazards are presented on her SmartPhone; she selects the hazard type and is then asked “Are you next to the hazard?” She replies “Yes” and the location of the hazard is entered automatically and the foreman in charge of that area and activity is shown, she selects Joe as the hazard owner and sets a fix time of 1 hour.

Sue’s SmartPhone alerts her that the sub-contractors undertaking the work, DrainIT, have not fenced off their excavations on other BuildIT sites in the U.K. She decides that she should inform the BuildIT Health and Safety Manager and selects “Escalate” on her SmartPhone. She details the problem using the keyboard on her sleeve and then selects “Submit”.

Joe receives an alert with details of the hazard and contacts Fred asking to meet him at the excavation to remedy the problem. As Fred and his gang walk across the site to the excavation their phones start to siren and a message appears notifying them that they have walked into a danger zone where crane operations are going on. The crane operator is also alerted and he halts work immediately until the gang is a safe distance away.

Joe meets the gang at the excavation and once the excavation has been fenced off, he responds to the hazard alert by entering Y on his SmartPhone. Work continues with the manhole. Fred notes that the invert level of one of the pipes is not going to be the same as the level on the manhole. He contacts Joe who comes back to view the problem. Joe is unsure of what to do and decides to contact the drainage designer. The presence awareness function on his SmartPhone lets him know that Peter is in a meeting, but that

Jane is available and at her desk. Joe instigates a video call with Jane and shows her the problem. Using the location information, she is able to instantly pull up the relevant plans and decide on a remedy to the problem: a zero was missing!

Work continues and data held within the central project model are automatically updated as each task is completed e.g. the progress plan, O&M records and resource utilisation. Sophie notes that DrainIT are consistently ahead of schedule and readjusts the project estimated finish time accordingly. She knows that this information can be used on the next project BuildIT undertake, giving the client more confidence in the budget and programme.

Five o'clock is fast approaching and Joe is pleased that his SmartPhone is still operating on full power thanks to his solar panel jacket. He receives an alert to let him know that the step-irons have arrived on site; he still thinks it is clever how this happens as the supplier drives through the site gates. Checking the programme, he decides that this work can be left until tomorrow and heads home with the thought of having to type up paper-work at the end of the day a distant memory.

5.2 Industry feedback

The construction industry contributors were senior employees of contractors (10) and consultants (2). There was a split of opinion with regards to how plausible the scenario was (Table 2) and several barriers to the scenario being realised were suggested (Table 3). However, the industry representatives also suggested several additions to the scenario which they perceived as being useful to them in the future including integration with other project systems/procedures, taking advantage of technological advances, and further processes which could be improved using mobile technologies (Table 4). Together these results indicate that the industry representatives can see advantages of using mobile technologies in construction, however, some perceive that the barriers may be insurmountable.

Table 2: Industry representatives' reactions to the scenario

Plausible	Neutral	Implausible
"Fairly close to what we would like. Young engineers are really pushing us for this technology and we are not currently in position to deliver or do not have adequate funds."	"I could always see a way in for new technologies such as this, particularly for materials consolidation, which I believe initially is the way into the industry… I do believe that your scenario is utopia and I would see people within the industry being skeptical of this example. I hope it will be reality sooner rather than later."	"…my impression is that this is much too hopeful a scenario apart maybe from some trial/ research funded situations. ...despite the availability of mobile phone technology, real, productive communication still to a large extent occurs in face-to-face situations."
"Interesting, not too futuristic either. You could perhaps build in a time tag - e.g. a reference to someone checking the 2006 world cup footie scores / watching a goal playback on their phone?"		"Your scenario sounds very futuristic - it will be interesting if things ever do progress to this level of sophistication on site."
"Many of the concepts which you have covered are currently being developed in our company."		

Table 3: Barriers to the scenario being realised

Barrier	Example feedback
Lack of clear leadership/critical mass	"No company profits from developing a system which everyone else can benefit from and most companies are too small to do their own bespoke development. Therefore there is no clear mechanism from within the industry of providing the standardisation necessary to allow a mass market to develop, which is what IT companies need in order to bring the cost down."
Resistance to adopt common systems	"Once some companies refuse to participate in the system, then it starts to break down for everybody - extranets are a classic example of this."
The fragmented nature of the industry	"…this is caused by the large number of companies in the Construction industry, and their widely varying levels and types of technology adoption. If we are to aspire to the same level of standardisation and integration as exists in the automotive industry, for example, then there needs to be more consolidation of companies, and the major customers/ contractors have to impose minimum requirements."
Resistance to change	"We need to address the "we have always done it this way", or "we don't do it like this with ABC Contractors" mentality combined with "I don't have time to change".
Safety concerns	"…our Safety Manager banned the use of Mobile Phones on all our sites, except for in very limited locations, and this makes a lot of the things in the scenario impossible to achieve."
Ease of use	"…the size of screens on SmartPhones and how readable the information is. The theory sounds fine, but I am not so sure about the practice. … I think that enabling point of activity workers should improve that validity of the information and make them feel more valued and part of the team, providing it is done in a way that they find easy to use. Our experience to date with PDAs is that the preference would be to throw them in the canal!"
National databases incomplete/non-existent	"The current situation is that there are so many services that are in the ground in an unknown state that it would /could take a very long time to have a database that would be really meaningful. However, Ground Penetrating Radar GPR could be used to scan new sites into a local database and build up the data required gradually."

Table 4: Suggested additions to the scenario

Integration with other project systems/procedures	Taking advantage of technological advances	Further processes to be addressed
"Automatic generation of orders from the details in the project model, alerting the Site Manager when orders are to be placed, giving them the option of sending the order to a supplier or not"	"Voice recognition will become more common and hence the need for Sue's fabric keyboard would be eliminated"	"Electronic daily diary; allocating time against scheduled activities and un-productive time"
"Automatic notifications to the QS so he can go out onto site and measure what had been completed once. Or maybe there is no need to go on site as it has already been covered in an earlier process"	"A translator into Lithuanian, Polish and other languages would also be useful so that foreign operatives can have a better chance of understanding what they are being asked to"	"Preventative maintenance using RFIDs (discussed earlier in this paper)"
"Deliveries should be booked automatically at the same time the task is assigned based on an estimated completion time and then confirmed/cancelled by Joe"		"Electronic receipt of goods received notes" (discussed earlier in this paper)
"Data feedback into KPI records to demonstrate continuous improvement"		"Snagging/Defect management" (discussed earlier in this paper)
		"H&S monitoring and auditing" (discussed earlier in this paper)

6 THE IMPLICATIONS OF AN INCREASED USE OF MOBILE IT

With any introduction of new technologies into the construction industry the technology itself is only part of the solution, the effects on the people and processes involved should also be considered. The following sections highlight three areas which should be considered as the uptake of mobile technology solutions increases; the potential for new islands of automation; the effects on our human resources and the potential impact on knowledge management initiatives.

6.1 New islands of automation

The use of information technology within the construction industry has seen the isolated development of functional, departmental or organisational solutions. This has resulted in the so called "islands of automation" illustrated by Hannus (1998a). In recent years the drive towards standards and interoperability, aided by the advent of the internet, is trying to provide bridges to link these islands together.

Ad-hoc development of isolated, function driven, mobile solutions for the construction industry risks the creation of a new archipelago; numerous small islands of solutions that do not feed back or link to existing back-end systems. The solution providers should be aware of this issue and look to provide solutions that can link into a variety of core IT systems e.g. collaboration tools, project models and knowledge management systems. This is imperative, not only to facilitate the uptake of these solutions, but also to gain the maximum benefit from these new sources of information to aid the seamless transition of information and processes between life cycle phases, provide better process understanding, reuse past project knowledge in new developments and achieve process improvement.

6.2 Human Resources

The successful implementation of new technologies and the resulting new ways of working will require very different skills of future field leadership workers. The challenge for construction goes beyond producing employees who are simply computer literate and can therefore deploy the technological innovations developed by the IT sector. It calls for engineers and professionals who are astute in their areas of specialisation and equally competent to devise the IT-based innovative solutions that will address the industry's operational weaknesses from a construction standpoint (McCaffer & Edum-Fotwe, 2003).

The CITB (2003) have recognized that the development and adoption of new technologies will affect both manual and non-manual occupations. For the manual worker this may mean new skills in production and quality control will be required, as construction becomes more mechanised and working tolerances greater; for example in the use of automated, GPS guided construction machinery. For the non-manual worker; architects and designers will need to work more closely with suppliers and contractors to integrate feedback, improvements and new ideas into the design. On site, construction managers and foremen will need to make more use of information and communications technology to schedule and report on work, and will require organisational and interpersonal skills to enable collaborative working amongst multi-disciplinary teams. The attitude of "that's the way we've always done it" will no longer be acceptable and an openness and input to new ways of working will be expected.

The current skills shortages could be addressed two-fold. Firstly, mobile technologies which enable productivity improvements could reduce the resources required, and secondly, as the construction industry becomes a safer, more efficient and innovative place to work in it should begin to attract more people with the right skills.

6.3 Knowledge Management

The importance of knowledge management has been recognized by the construction industry and is seen as a mechanism not only to avoid reinventing the wheel but also to encourage innovation and overall improvement. Construction projects are often unique in macro terms (e.g. context, client requirements, etc.) but similar in a micro context; thus the lessons learned during their execution should be reused in other projects (Kamara *et al.*, 2003).

Recent workplace innovations of a general nature such as employee involvement and empowerment, has resulted in greater recognition that workers at all levels of the organisation are a significant source of creative thinking (Kotter & Heskett, 1992). Consequently, the traditional division of work between thinking (white collar) and doing (blue collar) is gradually melding, requiring all workers to become part of an organisation-wide collaboration process (Leimeister *et al.*, 2001).

This has also been recognized in construction, however, the live capture and reuse of construction project knowledge has remained a major challenge that has not yet been adequately addressed (Udeaja *et al.*, 2004). Mobile technologies could provide the link to workers at their point-of-activity so that lessons learnt as the project progresses are captured immediately. This not only provides information to improve future projects, but the real-time knowledge can also be incorporated in future phases of the current project. It should be noted that some form of validation process should take place to ensure that a 360 degree viewpoint of the situation is represented.

The extension of knowledge management systems to point-of-activity workers could dramatically increase the number of people inputting into the knowledge bank, so that not only those that attend meetings are included. This will also serve to ensure that knowledge is gained “from the horse’s mouth” rather than a sanitised, second-hand version.

7 Conclusions

This paper has illustrated that many of the improvements wished for in construction change initiatives can and are, in isolated cases, already being facilitated by enabling point-of-activity workers to participate in the electronic flow of information using mobile technologies. Although this is not the only solution to the problems to be addressed, it does offer the potential of significant improvements in reducing construction time and cost, defects, accidents, waste and operation and maintenance costs whilst improving predictability and productivity through for example:

- access to accurate up to date information at the point of activity reducing the cost of remedial work through doing it right first time;
- auto-ID of materials enabling faster location and accurate identification, reducing wasted materials through loss, damage or oversupply;
- real-time accident and near miss reporting enabling a proactive approach to health and safety on site;
- reduction in down-time due to unforeseen problems through enabling instant and meaningful communication with off-site personnel;
- proactive maintenance scheduling and remote delivery of work orders;
- provision of accurate real-time progress and cost information which can inform later project stages and/or future projects.

The industry response showed that although there was enthusiasm for the future vision, not everyone agreed that these technological improvements were viable even though some companies were already looking at implementing some of the proposed solutions. The barriers identified were common to many IT applications in construction; therefore the achievement of the future vision will be dependent on demonstrating tangible benefits at an individual, company, project and client level.

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APPENDIX 5: SUMMARY OF SURVEY RESULTS

A summary of the survey results in relation to each of the survey objectives is given below. Further details of the survey and its results can be found in Bowden (2002).

Objective 1: Obtain a sample of respondents that are representative of the site-based personnel population.

Results: Analysis of the returns indicated that there was no evidence that sample responses were not representative of the target population at a 5% significance level. However, the analysis showed that the age-group '55+' and the job-type 'foreman/works manager' may be underrepresented, based on the relative numbers of staff on the M6 Toll, although there were no statistics available with which to confirm this.

Objective 2: Identify the paper-based tasks that are commonly undertaken on a construction site.

Results: Site-based personnel are both recipients and producers of paper-based information. The paper-based tasks that they carry out in their normal work were numerous (85 different tasks were identified). The most commonly identified tasks were completing data collection forms (25%), dealing with correspondence (18%), viewing and reviewing drawings (13%), and reading and writing specifications (6%).

Objective 3: Identify the information that site-based personnel would like to have access to whilst on site.

Results: Documentation to which site-based personnel would like to have access in the field is related to the paper-based tasks that they carry out as part of their normal work. This supports Tenah (1986) who found that information needs are inextricably linked to the management responsibilities of each member of the project team.

The document types that site-based personnel would find most useful to have access to/record in the field (out of the office) were drawings (24%), data collection forms (12%), correspondence (8%), progress information (7%) and specifications (7%).

Objective 4: Identify the views of site-based personnel about communications in the construction industry.

Results: The main issues identified as having an adverse effect on communication in construction were information transfer (22%), attitudes (16%) and protocols (10%). Within these themes, the barriers to communication cited by Roberts & O'Reilly (1978), Guevara (1981) and Murray & Thorpe (1996) were all identified: lack of feedback, over-load, under-load, gate keeping, distortion and accessibility.

26% of respondents suggested that the drawing distribution and approval process required improvement, especially the distribution of drawings to site-based personnel. 24% of respondents suggested more use should be made of IT and several suggested that IT in use currently was not user-friendly enough.

Objective 5: Obtain a measure of the IT literacy of site-based personnel.

Results: The overall levels of access to IT are high with 83% of survey respondents having direct (unshared) access to a computer at work, and 89% having access to the Internet. This compares well with the results of the Building Centre Trust Survey (1999) where 78% of contractors had direct access to a computer and 80% had access to the Internet.

The IT literacy measure used in this survey illustrated that 'foremen/works managers' and the age group '55+' have the lowest level of access, usage and knowledge. However, these results should be treated with caution since these groups were underrepresented in the sample.

69% of the respondents have received no formal IT training; they either taught themselves or learnt through colleagues. Therefore, although 68% of contractor firms say they have an IT component within their management training programmes (Building Centre Trust, 1999) this does not appear to be provided to the majority of site-based personnel.

78% of the respondents thought that further IT training would be beneficial. This compares with 21% of respondents (all construction profession companies) to the Building Centre Trust survey (1999) that identified more training as the single development that would most encourage greater use of IT.

Objective 6: Understand the attitudes towards the use of mobile (data and voice) communications on site.

Results: 80% of site-based personnel use a mobile phone at work. This compares with 93% identified by Newton's survey (1998) in Australia; however, only 29% of phone/radio users actually keep a record of the content of their calls and, of those that do, 24% only keep records of the call costs. This could be an important source of lost information.

26% of the respondents had used a hand-held computer before, however, it was not specified whether this was for personal or business use. Only 12% owned their own. Those who had their own had used it for a variety of purposes, but predominantly contacts (29%), diary (25%), setting out/surveying (13%) and email (6%).

82% of the respondents thought that hand-held computers could be used in a construction environment; however, 36% thought that they should be more rugged (i.e. dustproof, waterproof, shockproof, temperature resistant and durable). Figure A1 shows the tasks that the respondents thought a hand-held computer could be used for: data collection (31%) and viewing drawings (19%) were the most commonly identified tasks.

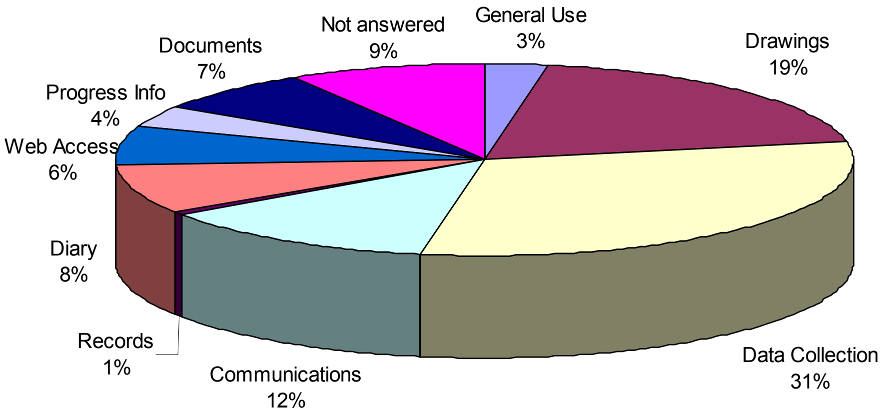

Figure A1: Tasks suggested as suitable for hand-held computers

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