USING MOBILE COMPUTING FOR CONSTRUCTION SITE INFORMATION MANAGEMENT

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ABSTRACT

In recent years, construction information management has greatly benefited from advances in Information and Communication Technology (ICT) increasing the speed of information flow, enhancing the efficiency and effectiveness of information communication, and reducing the cost of information transfer. Current ICT support has been extended to construction site offices. However, construction projects typically take place in the field where construction personnel have difficulty in gaining access to conventional information systems for their information requirements. The advances in affordable mobile devices, increases in wireless network transfer speeds and enhancements in mobile application performance, give mobile computing a powerful potential to improve on-site construction information management.

This research project aims to explore how mobile computing can be implemented to manage information on construction sites through the development of a framework. Various research methods and strategies were adopted to achieve the defined aim of this research. These methods include an extensive literature review in both areas of construction information management and mobile computing; case studies that investigate construction information management on construction sites; a web-based survey for the investigation of the existing mechanism for on-site information retrieval and transfer; and a case study for the validation of the framework.

Based on the results obtained from the literature review, case studies and the survey, the developed framework identifies the primary factors that influence the implementation of mobile computing in construction site information management, and the interrelationships between those factors. Each of these primary factors is further divided into sub-factors that describe the detailed features of relevant primary factors. In order to explore links between sub-factors, the top-level framework is broken down into different sub-frameworks, each of which presents the specific links between two primary factors.

One of the applications for the developed framework is the selection of a mobile computing strategy for managing on-site construction information. The overall selection procedure has three major steps: the definition of on-site information management objectives; the identification of mobile computing strategy; and the selection of appropriate mobile computing technologies. The evaluation and validity of the selection procedure is demonstrated through an illustrative construction scenario.

KEY WORDS

Construction information management, construction sites, construction personnel, mobile computing

ACRONYMS / ABBREVIATIONS

3G	Third Generation
Auto-ID	Auto-Identification
DTI	Department of Trade and Industry
DECT	Digital Enhanced Cordless Telecommunications
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
PPC	Pocket Personal Computer
ROI	Return on Investment
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
WPLAN	Wireless Personal Area Network
WWAN	Wireless Wide Area Network

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CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

This chapter sets out the background of the research. It introduces the general subject domains, research aims and objectives, research triggers, areas and scope, and definitions of the terms used in the research. Finally, the structure of the thesis is presented to provide clarity and direction to readers.

1.2 BACKGROUND TO THE RESEARCH

The motivation for this research stems from the need to improve the efficiency and effectiveness of the construction process with regard to the problems associated with fragmentation in the construction industry. The need for improvement has led to the introduction of new business processes that focus on the use of information technology. This research focuses on the implementation of mobile computing technologies, which is seen as the potentially effective key to the improvement of information management on construction sites.

1.2.1 THE NEED FOR CHANGE IN THE CONSTRUCTION INDUSTRY

The construction industry is defined broadly as a sector that includes the construction materials and products; suppliers and producers; building services manufacturers, providers and installers; contractors, sub-contractors, professionals, advisors and construction clients and those organisations that are relevant to the design, build, operation and refurbishment of buildings (DTI, N.D.). With the consideration to national economy, the UK construction industry represents a major economic sector that has significant contribution to the national economy accounting for 9.6 per cent of Gross Domestic Product (GDP) (DTI, 2005; NS, 2005). The specific features that differentiate the construction industry from traditional manufacturing industries include its fragmentation, reliance on casual labour, unpredictability, complex structure, separation of functions, dependency on several industries, long production cycle, transient organisation, mobile operatives and equipment, and multi-party operations (Kwakye, 1997).

The construction industry needs to be improved because of the problems that exist in the industry, the challenges it faces, and the key drivers for change in the industry. Egan's report (Egan, 1998) identified several existing problems in the industry including low profitability, little investment in research, development and capital, crisis in training, and client dissatisfaction. The National Audit Office (NAO, 2001) summarised a number of challenges the industry faces. These include more consideration of end users, better integration of the various stages, partnering between clients, contractors and consultants, longer term relationships between clients and contractors, better integration of the construction supply chain, and greater use of prefabrication and standardised building components. From a global perspective, Flanagan (2004) identified nine key drivers including urbanisation, ageing population, rapid technological and organisational change, environmental and climate change, the shift from public to private, the knowledge economy and information overload, technologies for tomorrow, people, safety and health, and vulnerability, security corruption and crime.

According to key reviews of the UK construction industry (Egan, 1998; Latham, 1994; Levene, 1995; NAO, 2001), the construction industry can be improved through partnering, the improvement of construction processes, and the improvement of performance. The National Audit Office (NAO, 2001) set key targets for improvement in the construction industry. These include the increase in client satisfaction with product and service, reduction in defects, increase in predictability of cost and time, increase in profitability, increase in productivity, increase in safety, and reduction in construction cost and time.

1.2.2 INFORMATION AND COMMUNICATION TECHNOLOGY IN CONSTRUCTION

Information Technology has been recognised as one of the key factors in improving the performance of the construction industry. However, the research of information technology in construction (ITC) is a relatively young territory and still struggling to define its position within the whole academic disciplines (Björk, 1999). There are many researchers who have discussed what is meant by ITC (Björk, 1997; Björk, 1999; Brandon et al., 1997; Hannus, 1996; Turk, 2002; Turk, 2006; Turk and Cerovsek, 2003).

They defined the ITC domain through two approaches: the top-down approach that uses existing theories as the basis for the definition, and the bottom-up approach that identifies and groups known research themes through a bibliographical analysis.

There are many researchers that aim to identify current ITC research issues (Amor et al., 2002; Ekholm, 2002; Howard, 2003; Turk, 2006; Turk and Cerovsek, 2003). Regarding the retrospective analysis, Amor et al. (2002) and Howard (2003) identified three key themes for current ITC research:

- The modelling of processes and products and the integration of this with visualisation and standardisation of information life-cycles.
- Issues associated with implementation, adoption and behaviour and management of technology.
- Re-engineering of processes and the search for integrated supply chains.

One of the key ITC research themes is the Computer Integrated Construction (CIC). The goal of Computer Integrated Construction (CIC) is the vertical integration of data, design decisions and knowledge through all phases of facility development to improve efficiency; therefore, facilities can better meet the cost, schedule, and technical performance objectives of their users (Kamara et al., 1996). This involves the use of information technologies to integrate the management, planning, design, construction, and operation of constructed facilities. Research projects in this area include ATLAS (Greening and Edwards, 1995), COMBINE (Augenbroe, 1995), RATAS (Björk, 1993), ICON (Aouad et al., 1994), COMBI (Scherer, 1995), OPIS (Froese and Paulson, 1994), SPACE (Faraj and Alshawi, 1999), WISPER (Faraj et al., 2000), and COMMIT (Brown et al., 1996). Augenbroe (2002) discussed different integration directions and their implications for the product and process modelling, and provided requirements for future design analysis integration. These requirements include the user-centric approach, the workflow-centric approach, explicit definition and management of analysis 'scenarios', scenario specific building simulation model interfaces, easy generation of 'internal' data interfaces, the tool independent system architecture, support of incremental design analysis cycles, and user controlled gateways to design information.

With the development of information technologies and research approaches in the area of ITC, a vision for the future of ITC is necessary to illustrate how further developments in IT technologies can have a influence on construction processes and projects to be executed in different ways. The emerging IT technologies for the collaboration in improving the effectiveness and productivity of information communication between project team members across project life-cycle include the semantic Web, XML Web services, GRID Computing, Intelligent Agent, Mobile Computing, Ubiquitous Computing, and Advanced Collaborative Visualisation Systems (Anumba et al., 2004). Sarshar's research (Saha and Mukherjee, 2003; Sarshar et al., 2000; Sarshar et al., 2002) discussed a vision consisting of seven key themes for IT technologies in construction information management. These key themes include product and process model driven, life-cycle thinking and transition, knowledge management, internet, visualisation, simulation and what-if analysis, and process improvement.

In order to analyse and measure the process of using IT in construction, Benedict et al. (2001) has set out goals for the industry. The short-term goals include the improvement of information availability and decision making, reduced impact of mistakes, and improved ability to respond to changing conditions. The medium-term goals are to reduce the number of redundant tasks and to bring the necessary stakeholders on board at the right time. The long-term goals include enabling collaboration of entire chains of performers without re-entry of data, substantial reduction of rework, substantial improvement in project cycle time, the ability to handle increasingly complex projects, vastly reduce risk, and greatly increase project value.

1.2.3 CONSTRUCTION INFORMATION MANAGEMENT

There are many researchers who have attempted to identify and categorise construction information from different perspectives. From the organisational aspect, construction information can be grouped into three categories: technical information, commercial information, and management and control information (BT, 1995). For construction personnel's information needs, Tenah (1986) carried out his research focusing on the responsibilities and the information needs of key construction personnel from the Chairman of the Board of Directors to the foreman in the organisation. Several researchers (Kangari, 1995; Sargent, 1993; Tenah, 1984) focused on the categorisation of construction documents existing in construction organisations and the analysis of each type of document to identify construction information it contains. Kamara (1999) identified the involved construction professionals and their information needs for each stage of the construction process. Construction sites are information intensive environments and on-site information can be summarised into various categories, such as RFI (Request for Information), materials management, equipment management, cost management, schedule and means and methods, jobsite record, submittals safety QC/QA, and future trends (de la Garza and Howitt, 1998; Scott and Assadi, 1999).

A number of researchers (IAI, 2002; O'Conner and Tucker, 1986) focusing on the construction industry suggested that one of the major factors for the inefficiency in a construction project is the problems arising from the transmission of construction information. Others (Dawood et al., 2002; Gyampoh-Vidogah et al., 2003; Mead, 2001; Rezgui and Zarli, 2001) have shown that the accurate and efficient management of construction information is one of the keys to achieving successful construction projects. Therefore, the efficiency and accurate of information management is crucial to the construction industry.

Research in the area of construction information management has developed and practiced a number of approaches, practices and technologies. These research issues include information flow modelling (Baldwin et al., 1999; Fisher and Yin, 1992), construction document management (Björk, 1993; Bohms et al., 1994; Joia, 1998; Rezgui, 2001; Rezgui and Debras, 1996), product modelling (CIMsteel, 1993; EDICON, 1991; Greening and Edwards, 1995; IGES, 1991; ISO, 1993; NEDO, 1989), Groupware System (Marache et al., 2001), knowledge management systems (Berney and Ferneley, 1999; Skyrme, 1999; Watson and Marir, 1994), and Web-based project management systems (Mead, 2001; Nitithamyong and Skibniewski, 2004; Walker and Songer, 1997).

However, there are still a number of problems existing in current construction information management. Communication methods between project participants are inefficient (Latham, 1994), and small or medium sized contractors suffer from the result of poor information exchange and control systems (Kangari, 1995). In addition, information provided during the contract process are almost always incomplete, which leads to long tending and results in inaccurate cost estimation (Finch et al., 1996a). The reason for the inefficient progress in the area of project management is often not well understood, because the existing models of the design process are inadequate if a detailed understanding of information-related events is to be obtained (Baldwin et al., 1999), and because the industry has focused on general quality management, although clients are more concerned with information providing and exchanging (Laitinen, 1998). Moreover, Newcombe and Landford (1990) expressed the view that the primary tasks of all organisations were affected by the internal culture of the business, but the challenge is how to reconcile the human, organisational and technical factors when managing information systems. Based on previous research, Gyampoh-Vidogah (2003) grouped existing problems into five categories: inability to develop information management policies; cultural issues; barriers to IT adoption; ill-conceived business process techniques; and inability to reassess new systems and IT infrastructures.

The traditional approach to construction procurement has resulted in a separation between the design and construction organisations and between the design and construction phases. The success of concurrent engineering for resolving the separation between design and production in the manufacturing industry has led to the motivations for its application to the construction industry (Anumba et al., 1997; Anumba and Evbuomwan, 1995; de la Garza, 1994; Kamara et al., 1997). Principles of integrated design and construction require effective communications at the task level between the work point and the design team. Only when the task-level bottleneck of information communication is resolved can the benefits of applying concurrent engineering in the construction industry be achieved on a larger scale (Elvin, 2003). However, the construction industry still needs new solutions to the problem of information communication and exchange on construction work sites (Bowden et al., 2004; Miah et al., 1998; Singhvi and Terk, 2003). Current IT support have been extended to construction site offices, but construction personnel on sites still have difficulties in gaining access to conventional information systems. The emergence of Mobile Computing has the potential to deal with the separation between site offices and work sites, and to improve the information communication between the fieldworkers at the point of work and the off-site collaborators in building design.

1.2.4 MOBILE COMPUTING IN CONSTRUCTION

For the achievement of integration between site offices and work sites and integrated design and construction, mobile computing has the potential to extend the boundary of IT support from site offices to work sites. With the support of wireless networks, construction personnel can use mobile computers coupled with mobile application software to gain access to the organisational information system anywhere on construction sites anytime it is required.

Current research on mobile computing usually focuses on the detailed aspect of mobile computing technologies or the development of mobile computing solutions for single or several construction processes. Research issues on mobile computing in construction include the following:

- Research on mobile computing technologies and their implementation in the construction industry includes the context sensitive (Menzel et al., 2002; Menzel et al., 2004; Oloufa et al., 2003; Singhvi and Terk, 2003); speech recognition (Kondratova, 2004; Reinhardt and Scherer, 2000; Sunkpho and Garrett, 2000); IP Telephony (Beyh and Kagioglou, 2002; Beyh and Kagioglou, 2004); wearable computer (Burgy and Garrett, 2002; Fuller et al., 2000; Garrett and Sunkpho, 2000; Miah et al., 1998; Mills and Beliveau, 1998; Reinhardt et al., 2000); Bar-coding technology (Finch et al., 1996b; Marsh and Finch, 1998; McCulloch and Luepraser, 1994; Skibniewski and Wooldridge, 1992; Stukhart and Cook, 1990; Tserng and Dzeng, 2005; Wirt et al., 1999); wireless sensor (Delsing et al., 2004; Domdouzis et al., 2005; Lee and Kang, 2006); mobile Ad-hoc network (Kuladinithi et al., 2004); and Ubiquitous Computing (Liu et al., 2003).

- Research that concentrates on the development of mobile computing systems for specific construction processes and the integration of them into existing IT-infrastructure includes the data collection system (Scott, 1990; Scott and Assadi, 1997; Ward et al., 2003; Ward et al., 2004); mobile construction management system (Kimoto et al., 2005); on-site problem solving system (Magdic et al., 2004); construction site inspection system (Mills and Wakefield, 2003; Sunkpho et al., 2003; Tung and Hwang, 2002); mobile operation support system (Meissner et al., 2002; Meissner et al., 2003); and mobile construction collaboration system (Johanson and Törlind, 2004; Zeeshan et al., 2004).
- Research that targets the feasibility of using mobile computing in construction includes the evaluation of mobile computers (Bowden et al., 2003; Elvin, 2003; Fuller et al., 2000; Pilgrim et al., 2002a; Shiratuddin et al., 2002); wireless network examination (de la Garza and Howitt, 1998; Deguine et al., 1999); evaluations for mobile computing system (Magdic et al., 2002); construction process comparison (Bowden et al., 2004; Saidi et al., 2002); and mobile computing practices in a real construction environment (Ward et al., 2003; Ward et al., 2004).
- Research that focuses on soft issues includes the investigation of potential tasks and construction processes for the implementation of mobile computing (ARUP, 2003;

Saidi et al., 2002); challenges of and barriers to using mobile computing in construction (Anumba et al., 2003; Magdic et al., 2002; Saidi et al., 2002); and benefits of mobile computing implementation (Bowden et al., 2006; de la Garza and Howitt, 1998; Olofsson and Emborg ,2004; Rebolj et al., 2001).

1.3 PROBLEM DEFINITION

Advances in IT technologies have increased the speed of information flow, enhanced the efficiency and effectiveness of information communication, and reduced the cost of information transfer. Current IT support has been extended to construction site offices. However, construction projects typically take place in the field where construction personnel have difficulties in gaining access to conventional information systems for their information requirements.

Construction sites are information intensive environments where actual construction processes and activities are carried out. Various construction personnel in the field are required to be mobile in order to conduct construction activities. Meanwhile, on-site individuals need large amounts of information ranging from project design drawings to personal diaries to support their ongoing work and to make decisions on construction processes. Therefore, the quality, quantity and timing of information communication are essential to determine the success of a construction project. However, traditional information management methods, which normally consist of the organisation and maintenance of paper-based documents, have constrained the efficiency and effectiveness of the on-site information communication and exchange.

As a potential technology, mobile computing is becoming a major research theme in the domain of Information Technology in Construction. However, most research in this area is focused on a detailed aspect or single facet of mobile computing in terms of the mobile computer, wireless network and mobile application. As one technology overtakes other technical solutions, it should be more consistent and reliable. Therefore, it is reasonable to concentrate on general concepts and internal relationships between the two areas of mobile computing and construction information management.

Because of the complex nature of the construction site environment, the variety of on-site information, and the features of mobile computing, mobile computing system designers have to consider many interrelated factors that can affect system performance in order to fulfil users' requirements. However, those key factors and their interrelationships are not clearly identified, and a detailed framework that contains the factors and indicates their links is necessary to provide guidance on the effective development and use of mobile computing for on-site information communications.
Current researchers have targeted this area from various perspectives through different research methods in order to explore the potential of applying mobile computing in the construction industry. However, this research is lacking in the area of how users can select appropriate mobile computing strategies to suit the characteristics of their own construction project.

Although many academic researchers believe that mobile computing can improve the efficiency and effectiveness of information communication on construction sites, the potential of the new technology has not been fully recognized by the industry. Therefore, mobile computing is not implanted on a broad basis by the construction industry except in some rare cases. Construction practitioners do not normally understand how mobile computing can be used to manage on-site information when applied to their own situations and fail to recognise how mobile computing can improve information communication in terms of increasing the efficiency for their own information needs and providing greater convenience for their information retrieval and transfer.

1.4 AIMS AND OBJECTIVES

1.4.1 AIMS

This research project aims to explore how mobile computing technologies can be implemented to manage information on construction sites. The research concentrates on the identification of all major factors and their interrelationships which impact on the design, implementation, and application of mobile computing in the management of information on construction sites.

1.4.2 OBJECTIVES

The specific objectives of the research project are:

1. to investigate the concept of construction information management;
2. to investigate the state of the art of mobile computing technologies and their practices in the construction industry;
3. to develop a framework to explore the use of mobile computing in construction site information management; and
4. to demonstrate the validity of the framework through an illustrative example.

1.5 PRIMARY RESEARCH AREAS

According to the research aims and objectives, problem definition, and research scope, the primary research area for exploration is the implementation of mobile computing in construction site information management. This research is cross-disciplinary and the primary research area needs to be set in broader contexts including several relevant research areas, such as information and information management; construction information and construction information management; mobile computing technologies; and mobile computing in construction. The review in these relevant areas ensures theories and practices from outside the construction industry can be learned and applied in this research project. Figure 1.1 shows the primary research area, relevant areas, and the cross and overlap of them, which will be reviewed and analysed in great detail in Chapters 2 and 3.

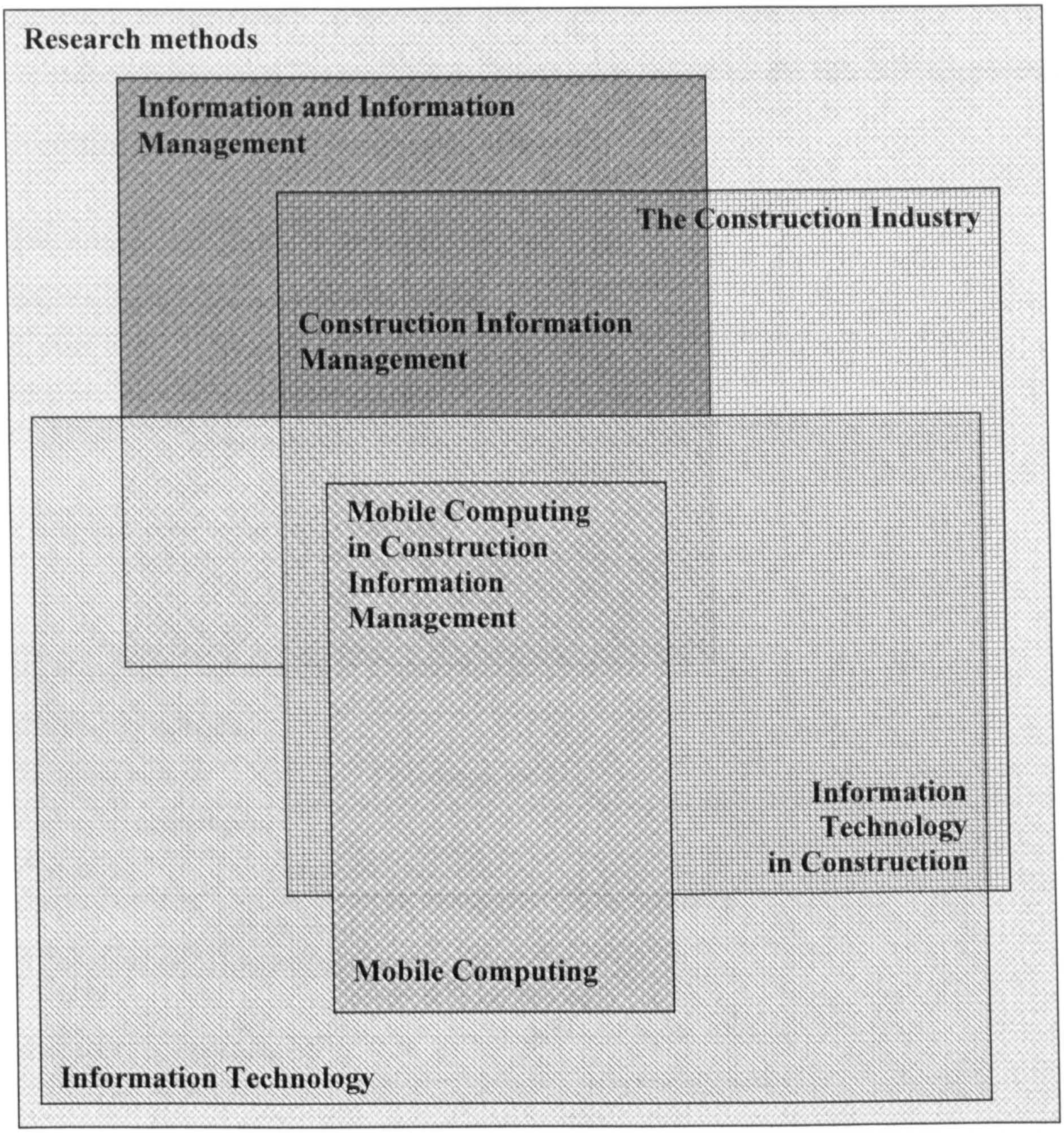


Figure 1.1 Primary research areas and relevant research areas

One of the ways to improve the industry's performance is the implementation of Information and Communication Technology (ICT) in construction information management. The domain of Information and Communication Technology in construction contains many research themes. As a new emerging technology, mobile computing has the potential to improve information communication on construction sites. As shown in Figure 1.2, the starting point of this research is derived from the area of Mobile Computing in Construction (MCC) that is the emerging research facet in the domain of Information Technology in Construction, of which the aim is to improve the performance of the whole construction industry.

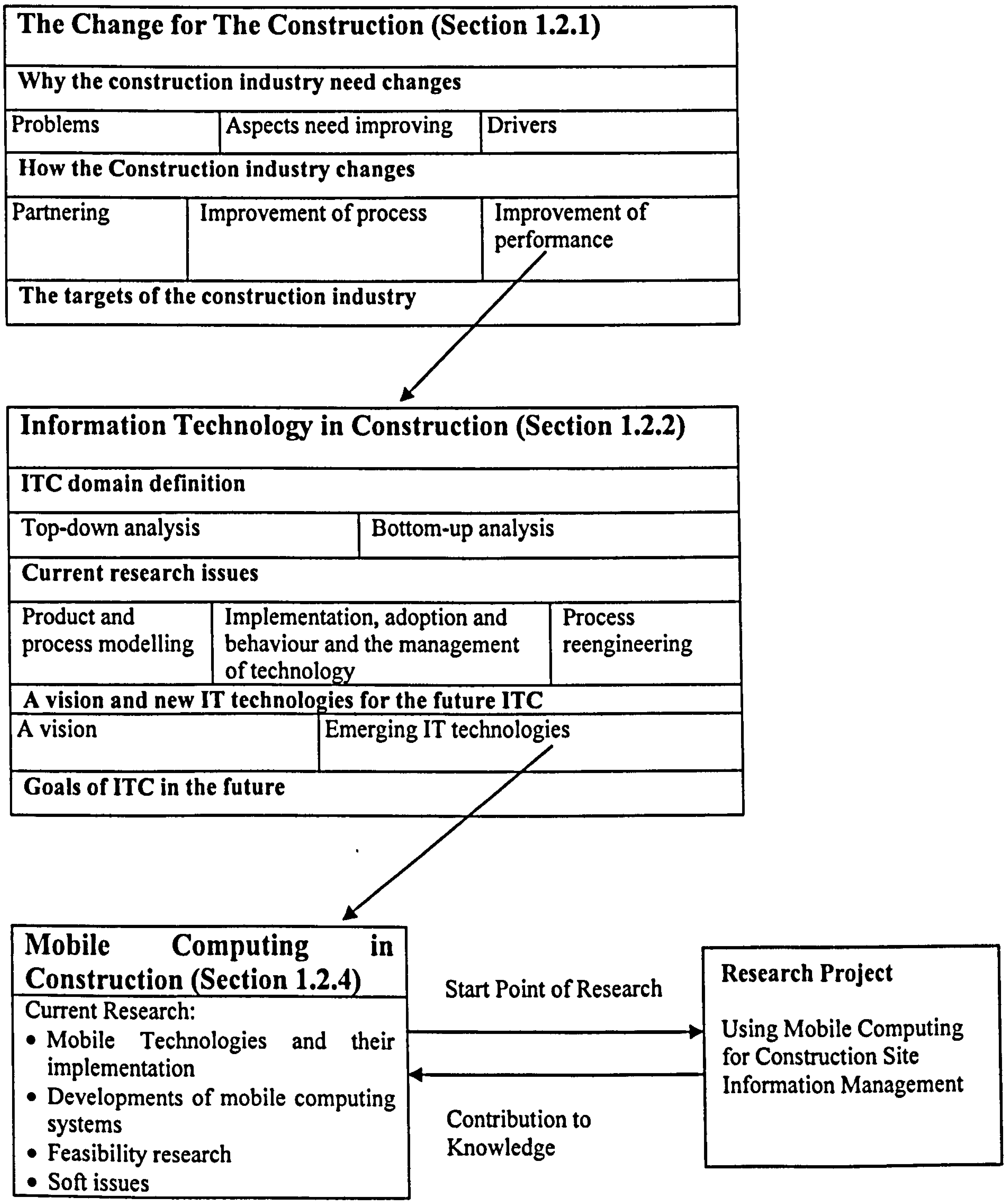


Figure 1.2 The starting point of research

1.6 RESEARCH SCOPE AND LIMITATIONS

This research is primarily focused on mobile computing, construction sites, mobile construction users, on-site information, and the interrelationships and interactions between them.

In this research, mobile computing is concerned with the combination of mobile computer, wireless network and mobile application. A mobile computer is a computer that can be used indoors and outdoors while the user is in motion and includes all kinds of pocket computer, palmtop and wearable computer, except conventional notebooks. Wireless networks exclude wired networks but include all kinds of wireless ones, which have sufficient bandwidth and can be accessed while in motion. Mobile application is the software that supports user's work processes with the awareness of user locations and responds to specific characteristics of mobile computers and wireless networks.

This research considers that a construction site comprises two main components: construction work site and site office. The construction work site refers to the areas of material storage spaces, actual operation places, equipment locations and other field operations outside the site office. The construction site office is the headquarters for managerial personnel, such as project managers, foremen, and engineers. The reason for dividing the construction site into two components is based on the consideration of the information flow boundary between work site and site office. The site office is an information intensive environment where all types of documents, contracts, drawings and specifications are stored. The work site is the area where actual construction activities are carried out. On-site individuals need to retrieve adequate information to sustain their operations and meanwhile transform sufficient information back to managerial people for project monitoring and control.

In this research, mobile users are potential users who use mobile computers to retrieve, process, collect and transfer information on construction sites. With the extension of Bowden's classification (Bowden, 2005), construction workers on construction sites can be defined into the following three categories:

- **Fixed Worker.** Fixed workers normally work at site offices, and use the desktop PCs or laptops with the connection to a fixed Local Area Network (LAN) or a Wireless LAN (WLAN) where cabling is not appropriate, which is termed "fixed wireless". Examples would include office based structure designers and architecture designers.
- **Semi-Fixed Worker.** Semi-Fixed workers normally use desktop or laptop at site office, but they have to move from place to place at construction work sites in-between working periods. Their communicational infrastructure can be either a fixed LAN at a site office or a WLAN or mobile network providing coverage in the area of a construction work site. Examples would include project managers and contract managers.
- **Mobile Worker.** Mobile workers normally use mobile computers, such as pocket PCs and tablet PCs, whilst moving around at a construction work site or remaining at a site office for short periods of time. Their communication infrastructure can be either a WLAN providing coverage in the area of work or a mobile network (radio or telephone). Examples would include foremen and site engineers.

The development of a framework only concerns the limited factors that have an impact on the implementation of mobile computing in managing information on construction sites. Because of the resource (i.e. time, budget, etc.) limitation of the research and the priority of the factors, other factors (i.e. cost, existing organisational information system, the type of project, etc.) that may affect the implementation of mobile computing are not included in this framework.

1.7 THESIS STRUCTURE

This thesis documents the research undertaken in fulfilment of the requirements for the award of PhD of Newcastle University. It is structured as follows:

Chapter 1 introduces the background of this research project, provides the starting point for this research in the research map, identifies the aims and objectives, justifies the need for the research and defines the research scope.

Chapter 2 provides an overview of previous work in the area of construction information management, and discusses the concept of information and information management and related issues of construction information and management.

Chapter 3 discusses the technical issues of mobile computing and the implements of mobile computing in construction, and demonstrates how this research builds on preceding research.

Chapter 4 discusses a range of research methodologies and justifies the adopted methodologies that are used in this research project. It also details the research process and documents the work undertaken to meet the research aims and objectives.

Chapter 5 summarises the research findings from the case study and the survey in the research process.

Chapter 6 presents a detailed explanation of the framework of using mobile computing for construction site information management.

Chapter 7 provides the application of the framework to select mobile computing strategies to suit the characteristics of the specific project, and examine the application of the framework with an illustrative construction scenario.

Chapter 8 concludes this research with a discussion of how the research has satisfied the proposed objectives and how the research has contributed to knowledge and practices.

Appendices include the published papers, examples of mobile computer and mobile application, and examples of case study and survey data.

CHAPTER 2

CONSTRUCTION INFORMATION AND MANAGEMENT

2.1 INTRODUCTION

In this chapter the conceptual definitions for information and information management will be introduced and their theories applied and extended into the area of construction information management. This is followed by the introduction of construction information management practices and technologies. Finally, the existing problems of construction information management and the need of new IT tools for integrated design and construction are discussed.

2.2 INFORMATION AND INFORMATION MANAGEMENT

Because this research concerns the improvement of construction information management, it is essential and helpful to learn theories from the area of information management and apply these theories in the new research area. This section will introduce the concept of information, discuss theories of information management, and provide the operational definitions for the research.

2.2.1 THE DEFINITION OF INFORMATION

Before discussing any theory of information management, it is necessary to understand what exactly is meant by information and how researchers can define the concept of information.

2.2.1.1 Early Efforts of Defining Information

The concept "information" has been variously defined for different purposes in early history, but no generally acceptable definition has been formulated. After the comparative study of 39 definitions of the concept "information", Wellisch (1972) found that only eight of them are necessary to define what they mean by "information" and all rest of them are circular definitions which are unnecessary in detailed discussion. He further argued that even the eight valiant definers of "information" do not succeed in arriving at an agreed-upon definition, nor do their definitions have any common elements. Based on Wellisch's comparison, the eight early efforts of defining the concept "information" are introduced and summarised as follows.

- The first to define the concept of information for the purposes of "Informatics" are Mikhailov et al. (1966) who stated that "*information could be defined as the objective content of the link between interacting material objects, which reveals itself in the transformed status of these objects.*" Wellisch (1972) commented that the first definition expressly includes a reference to the *change in the mind of people* that takes place when information is communicated, perceived and assimilated.

- In 1968, Hoshovsky and Massey (1968) stated that "*information is a process which occurs within a human mind when a problem and data useful for its solution are brought into productive union.*" Wellisch (1972) argued that this definition seems to suppose that the minds of human beings are constantly occupied with solving problems and that only such messages constitute information, which result in the birth of a solution to it.
- Hayes (1969) emphasized "information" as "*a slippery concept, amorphous, loaded with connotations and implications*" and it "*has had a variety of meanings*" yet "*we must have a suitable definition, even if it is at the most elementary level.*" After defining "data" as "*that which is recorded as symbols from which other symbols may be produced*", he goes on to define "information" as "*the result of processing of data, usually formalized processing.*" Wellisch (1972) commented that this definition leaves out what goes on in the mind of a person informed and stresses the mechanistic aspect of processing.
- Koblitz (1969) distinguishes between three kinds of information, which are "*semantic information (as a message)*", "*semantic information (as a process)*", and "*Documental information*". Wellisch (1972) pointed out that these multiple choices cannot hide the fact that the definitions are circular or ambiguous, or both.
- Yovits (1969) first stated that "*if the definition of information is nebulous, varied, and non-rigorous, then the definition of information science is even more nebulous, varied and non-rigorous*" and moved forward to define "information" as "*data of value in decision-making*" for the purposes of a generalised information system model. Wellisch (1972) criticised that his definition might be sufficient within the limits of his model, but it is not acceptable as a general definition of what Information Science is concerned with.

- Regarding meaningful or semantic information, Wersig and Meyer-Uhlenried (1970) defined "information" as "*reduction of uncertainty*", Wellisch (1972) argued that in this definition information is seen as a mechanistic process or as the result of such a process that the formulation leaves room for both interpretations.
- After distinguishing four different meanings of "information", Diemer (1971) then defined "information" as "*an absolutely non-mâterial entity which respresents a fact (real or imagined) and which ideally is made available to anybody, anywhere and at any time.*" Wellisch (1972) explained that this definition means anything a person might say, write, draw, or otherwise signal to other persons.
- Fairthorne (1965) proposed to treat "information" as a kind of null term which should not be used at all, and in a later paper he stated that "*information is a metaphorical designation for an amorphous mass of ill-defined different activities and phenomena.*"

From the review of early efforts at defining "information", the following considerations should be understood and considered carefully. These are: (i) There is no universal or unique way to define the concept of information. This means that different definers from various backgrounds have different understanding of the concept "information" and define it based on their own requirements. (ii) Any effort at defining "information" should consider its particular contexts or disciplines. (iii) In order to fully understand the concept of information, the definition should be explained, represented, compared, and linked to other related concepts such as data and knowledge.

2.2.1.2 Definitional Hierarchy of Information

According to the review of early efforts at defining the concept "information", the concept definition must take into account the differences in phenomena at different levels in the context structure. Therefore, Braman (1989) suggested a definitional hierarchy sequencing a choice of definitions for use in particular situations.

Braman (1989) then introduced three approaches to define the concept. The first approach is to choose one operational definition for uses in all situations, which is the most logical and easiest way. However, he argued that this approach unfortunately led to a political stance that will polarize the policy discussion at best, and exclude certain discussants from participation at worst. The second approach starts from the position that information is multifaceted, so that multiple definitions apply concurrently. Although this approach is flexible, Braman (1989) commented that this approach does not offer any concrete guidance in choosing from the many, a single operational definition for use in analysing specific fact situations or issues which have their own constraints and motivations. Finally, the third approach is the definitional hierarchy that is based on differences in level of scope (how broad a range of social phenomena is combined into the concept) and complexity (how variously articulated is the social organisation).

Based on the approach of definitional hierarchy, Braman (1989) divided information definitions into four broad groups: information as a resource, as a commodity, as perception of pattern, and as a constitutive force in society. The general characteristics, strengths and weaknesses of each of these types of definition are argued and discussed as follows:

- **Information as a resource.** Definitions of information as a resource are concerned with the treatment of information as a physical resource that can be processed. It is characteristic of definitions of this kind to be general in nature. The strength in defining information as a resource is that it is relatively easy to comprehend and it emphasises the uses that people make of information rather than its effects upon people and society. The weakness in treating information as a resource is that because information is not subject to physical roles, information and its creators, processors and users are viewed as discrete and isolated.
- **Information as a commodity.** Characteristics of defining information as a commodity include the profusion of terminology in use, and its increasing scope, penetration and domination. Because of the non-materiality of information, the problems of treating information as a resource are multiplied with the attempt to treat it as a commodity. These types of definition do not reach many of the critical phenomena in which information is involved, or effects of information creation, flows, processing and usage.
- **Information as perception of pattern.** Defining information as perception of pattern broadens the concept of information by adding contexts in which information has a past and a future and is affected by motive and other environmental and causal factors. The strengths of this type of definition are that it comes closer to the real world environment of information creation, processing, flows and use, and that it provides a starting point for quantifying and valuing information. The main disadvantage of definitions of information that treat it as perception of pattern is that they are relativistic in terms of the perception of pattern shifting from observer to observer, so that any use of such a definition must make explicit the point of view from which it is being applied.

- **Information as a constitutive force in society.** Definitions in this category grant information an active role in shaping context. Information is not just affected by its environment, but is itself an actor affecting other elements in the environment. The strength of this type of definition is that it is relatively friendly, enlarging the context in which users of other definitions work; but the weaknesses include the difficulty of quantifying events and effects and the ideological manipulation which is more directly apparent than in other types of definitions.

With the development of Information Science and the advance of Information Technology, the understanding of the concept "information" has been extended in great depth by researchers in various domains. Based on an intensive literature review, McCreadie and Rice (1999) identified and illustrated a range of information definitions, which are introduced as follows:

- **Information as commodity/resource.** Some disciplines treat information as a commodity, thing or resource that can be produced, purchased, replicated, distributed, manipulated, passed along, controlled, traded and sold. This type of definition is consistent with a model of sending information as a message from sender to receiver.
- **Information as data in the environment.** "Information" in other disciplines tends to be viewed more broadly available for interaction with human information processing capabilities, which include data in the environment such as objects, artefacts, sounds, smells, events, visual and tactile phenomena, activities, and phenomena of nature.

- **Information as a representation of knowledge.** "Information" is viewed as stored knowledge. The storage mediums include traditional mediums such as paper-based books and documents, and new electronic medium such as computer discs.
- **Information as part of the communication process.** Some disciplines treat information as part of human behaviour in the process of moving through space/time to make sense of the world. From this view, meanings are in people rather than in words or data. Timing and social factors play a significant role in the processing and interpretation of information.

In the discussion of defining the concept "information", the definitional processes are always explained and linked to other concepts such as data and knowledge. In order to provide insight in the understanding of the concept "information", it is necessary to compare those relevant concepts.

2.2.1.3 Comparison of Data, Information and Knowledge

The relationship between data and information is one of the major obstacles to provide an explicit set of definitions because both terms "data" and "information" are used either interchangeably as synonyms or with only slight differences. Court (1997) compared the definitions in different disciplines and summarised the differences between "data" and "information" within various contexts as follows:

- In areas of computer science and information science, scientists define data as containing information. Definitions of information in these contexts are always from the view point of binary choices and measured in bits-per-second or bits-per-signal. Scientists in these disciplines compare "data" and "information" as: "*Data are raw* *facts that have not been organised or cannot possibly be interpreted. Information is data that are understood*" (Benyon, 1990).

- In areas of bibliography and library, researchers define data as the actual piece of information required. For example, these statements include "*data or facts are the actual items of information required*" (Wall, 1986) and "*data are first condensed into information and from this information meaning is distilled*" (Keay, 1969).
- Researchers in other disciplines normally make distinctions between the two concepts. Wilson (1987) distinguished them by defining data as "*the representation of information independent of meaning*" and information as "*the data plus the meaning connected with it*". Benyon (1990) compared them as that "*data is the raw material*" and "*information comes from the relationship between pieces of data*".

Meadow and Yuan's view (1997) of the difference between data and information depends upon the recipient of the message. Generally, data usually means "*a set of symbols with little or no meaning to recipient*" and information is "*a set of symbols that does have meaning or significance to their recipient*". Meadow and Yuan (1997) further defined that data is: (i) "*a set of symbols in which the individual symbols have potential for meaning but may not be meaningful to a given recipient*", (ii) "*a set of symbols in which the individual symbols are known but the combination is meaningless: the semiotics are known, the syntactic are not*", or (iii) "*understandable symbols rejected by the recipient as being of no interest or value, typically because redundant or disbelieved*". Otherwise, the symbols are called information if they are "*understood, new, or meaningful to the recipient*".

Information and knowledge are often used as synonyms. From both the linguistic and philosophical view points, Machlup (1980) distinguished that information is "*the activity or process of informing and getting informed*" and knowledge is "*the state of knowing*". Court (1997) commented that Machlup's definition attaches the concept of communication to information, which suggests that "*information is dynamic*", and on the other hand, knowledge is a state, which "*is the property of the individual*". Generally, knowledge is viewed as "*the cumulation and integration of information received by any given entity*" and is "*what the recipient of a message has and what changes as a result of receiving information*" (Meadow and Yuan, 1997). "Entity" in this definition means that the receipt and processing of information includes animals and certain machines. Meadow and Yuan (1997) further defined knowledge as: (i) "*about a topic or information that*", (ii) "*about how to do something or knowledge how*", or (iii) "*about how to find information*".

2.2.1.4 Operational Definition and the Need for Information Management

This research adopts the view point that the definition of information should consider the differences in phenomena at different levels in the context structure. Therefore, this research accepts the definitional hierarchy based on differences in level of scope and complexity for the operational definition of information. According to the review of previous research (Braman, 1989; Buckland, 1991; Eaton and Bawden, 1992; Madden, 2000; McCreadie and Rice, 1999; Rowley, 1998), which contributes to the debates of defining information from different perspectives, the operational definition defines the concept of information from the following aspects:

- **Information as resource or commodity.** Information is transmitted in a message from a sender to a receiver. The message can be produced, purchased, replicated, distributed, sold, traded, manipulated, passed along, and controlled.
- **Information as data in environment.** Information is described as objects, artefacts, sounds, smells, events, visual and tactile phenomena, activities, phenomena of nature, which can be obtained from a range of environmental stimuli and phenomena.
- **Information as a representation of knowledge.** Information is described as documents, books, periodicals, some visual and auditory representations and abstractions of information. Traditionally the storage medium has been paper-based, but increasingly electronic medium are becoming important.
- **Information as a constitutive force in society.** Information is not just affected by its environment, but is itself an actor affecting other elements in the environment. Information is that which is not just embedded within a social structure, but creates that structure itself.

Information is important for both organisations and individuals in different domains. Several researchers have discussed the importance and requirements of managing information on the following issues:

- The undergoing globalisation and the rapid changes in industries, which include reducing the duration of product cycles, increasing development costs for new products, and taking greater risks with the potential for greater rewards, require organisations to operate within the increasingly complex, competitive and deregulated market place. In order to reduce reaction time and speed decision making, organisations require the intelligent processing and management of more information. Meanwhile, with the increased amount of knowledge, individuals become more and more specialised to a specific subject and need to deal with more and more information in this area. The fundamental problem that all organisations and individuals face is an exponential growth of information. Therefore, the solution is information management (Theodoulidis, 2000).

- As information is recognised as a valuable and self-regenerative resource in organisations, the appropriate management and use of information can stimulate innovation, speed product development, raise levels of productivity, ensure consistent standards of quality and through all of these means raise the relative level of competitiveness (Ravichandra Rao, 1999). There are several key factors that have led to the increased use and management of information for competitive advantage, such as the need for fast reliable information exchange, the evolution of guidelines, standards and protocols, the penetration of information systems into internal business processes, and the use of information technology to distinguish product and enterprise (Du Toit, 1998).
- The advances of technology and the wide dissemination of information lead to the information overload suffered by many organisations. They need to apply the strategies of information management to deal with this information chaos in their daily works. Information overload can affect individuals in two ways. First, the affected individuals may be unable to locate the information they need and it causes them to overlook what they would consider critical. Second, information overload may cause individuals to use the irrelevant information for decision-making. Therefore, the selection of appropriate information management strategy is essential for both organisations and individuals (Farhoomand and Drury, 2002).

2.2.2 THEORIES OF INFORMATION MANAGEMENT

This section aims to provide an understanding of the nature of information management and discuss the operational definition that will be used as the conceptual framework to explain the implementation of mobile computing in construction.

2.2.2.1 Information Management Definition

As discussed in the last section, there are many different considerations, viewpoints, and perspectives which surround the concept of information. Therefore, it can be understood that researchers from different disciplines give the definitions of the concept "information management" based on their own experiences and purposes. Some examples are introduced as follows.

From a personal information management perspective, Cronin and Davenport (1991) stated that "*In a sense all of us are information managers. We all manage information on the personal level which is formal and structured, as well as informal and less structured.*" Davenport (1988) extended this point by placing personal information management in an organisational context and stating that "*it may be viewed as a higher management function since it contributes to strategy, but on the other hand, it may be equally argued that it applies right down the line.*"

From the perspective of integrating the personnel and the organisation, Fairer-Wessels (1997) stated: "*Information management is viewed as the planning, organising, directing and controlling of information within an open system (i.e. organisation). Information management is viewed as using technology (i.e. computers, information* *systems, IT) and techniques (e.g. information auditing/mapping) effectively and efficiently to manage information resources and assets from internal and external sources for meaningful dialogue and understanding to enhance pro-active decision making and problem solving to achieve aims and objectives on a personal, operational, organisational and strategic level of the organisation for the competitive advantage and to improve the performance of the system and to raise the quality of life of the individual (by teaching him/her information skills, of which information management is one to become a global citizen).*"

From a multi-disciplinary perspective, Taylor and Farrell (1992) proposed some components of an information management construct that indicated the disciplinary influences on information management. Marchand (1982) also analysed the multidisciplinary perspective and argued that sciences of information include: information science, library science, computer science, informatics mathematical theory of communication, systems theory and systems analysis, operations research, cognitive psychology, artificial intelligence, robotics, cybernetics, decision sciences, semiotics and cognitive science.

From a technological perspective, Cronin and Davenport (1991) pointed out that "*information management involves systems*" and "*technologically information management relies on codified knowledge to produce formal representation of information entities which allow the automation of transaction processing, decision making and information retrieval.*"

As discussed above, researchers in various disciplines and from different perspectives cannot yield a unified view of the nature of information management. However, Rowley (1998) pointed out that disciplinary definers cannot avoid the consideration of the processing of information when seeking to define the concept "information management". He first referred to Curtis's categorisation of types of information processing, which included classification of data; rearranging/sorting data; summarising/aggregating data; performing calculations on data and selection of data (Curtis, 1989). Then Rowley (1998) argued that information management can be viewed as a response to and a search for new and improved means of controlling the information explosion and the resultant increasing complexity of decision making by improving the flow, the control, the analysis and the synthesis of information for decision makers. Finally, Rowley provided a formal definition of the concept "information management" (Rowley, 1988):

"The aim of information management is to promote organisational effectiveness by enhancing the capabilities of the organisation to cope with the demands of its internal and external environments in dynamic as well as stable conditions.

Information management includes organisation wide information policy planning, the development and maintenance of integrated systems and services, the optimisation of information flows and the harnessing of leading edge technologies to the functional requirements of end-users, whatever their status or role in the parent organization.

Information management has two dimensions, the management of the information process and the management of data resources."

This formal definition of information management defines its aim, scope and dimension, which is the theoretical base for her information management model that is adopted as the conceptual definition for this research.

2.2.2.2 Theoretical Development of Information Management

As discussed in Section 2.2.1.3, the concepts of data, information and knowledge are closely linked together. Based on the difference of data, information and knowledge, Theodoulidis (2000) classified information management systems into three generations: data base management systems, information base management systems and knowledge base management systems. These three generations provide the theoretical development and the increasing understanding for the concept of information management.

- **Data Base Management Systems.** Data is the raw, unsummarised and unanalysed facts, which contain and transfer information and knowledge. The first generation of information management system is the passive storage engine of large amounts of raw data, of which the storage mechanisms are the database based systems. Current business heavily relies on these reliable, mission-critical operational data management systems that are required to establish facts about certain objects and to provide quantitative aggregated data.
- **Information Base Management Systems.** Information is a set of symbols that have meanings or significances to their recipients. This means that data becomes information when it is interpreted by their recipients. Information is descriptive and relates to the past and the present. As a result of increasing demand for information and the focus on supporting decision making processes, information management

systems require new models of data (object based, logic based, spatial, temporal, text), new ways of processing data (data mining, text mining, visualisation) and new mechanisms to support integration. The second generation of information management systems evolves from the passive stores to more active systems by integrating available data and incorporating business contexts. These new kinds of system have the ability to analyse, integrate and distribute information to the appropriate people and processes.

- **Knowledge Base Management Systems.** Knowledge is the property of individuals and is viewed as the accumulation and integration of information received by any given entity. Knowledge is predictive compared to information that is related to the past and the present. Based on a certain degree of information relating to the past and the present, knowledge establishes a basis for the prediction of the future. As the next generation of information management systems, knowledge management systems integrate business context, market context, competitor and customer behaviour within a holistic framework that support learning, judgement and decision making. The central component of these systems is the knowledge base that incorporates the whole data about the company, systems, products, customers, suppliers and competitors.

For more detailed analysis, Chen (1998) classified the progress of information management into eight stages:

- The first stage is the physical control of information containers, essentially on paper.
- With mechanisation, simplification and replication, the second stage focused on the information containers, normally paper and paperwork.

- In the period of the 1920s and 1930s, the third stage progressed from the concentration on information containers in a universal and indiscriminate way to a more systematic and organised way.
- With the emergence of the computer, the fourth stage came with the management of automated information technologies.
- The fifth stage is a feature of the information explosion that is the result of the spread of computers and technologies such as microfilm and fiche, and early optical scanning devices.
- In the 1960s, the idea of the Management Information System (MIS) triggered the sixth stage of the evolution of information management. The Management Information System provided the promise of computer-based systems that contained all information that corporate management needed to run their business.
- In the 1970s, the seventh stage of information management was called information resources management; a new strategy for managing all necessary information in an enterprise. The key consideration of Information Resources Management is that information is the organisation-wide resource that is critical for the organisation to achieve its missions.
- The eighth stage during the history of information management is the idea of Knowledge Management that has caused great evolution on ideas, concepts, and approaches for information management. Knowledge Management is viewed as the discipline that promotes an integrated approach to identifying, managing and sharing all of an enterprise's information assets such as databases, documents, policies, procedures, and expertise and experiences resident in individuals.

2.2.2.3 Operational Definition of Information Management

This research adopted the definitional hierarchy as the operational definition for the concept of 'information'. Correspondingly, this research accepts Rowley's information management model (Rowley, 1998) as the operational definition for the concept of 'information management'. Rowley's model (Rowley, 1998) considers that information management has four different levels: information retrieval, information systems, information contexts, and information environment (see Figure 2.1). The four levels are discussed as follows:

- **Information retrieval.** Information retrieval is concerned with the view that the individual interacts with a system or range of systems or information sources to meet its specific conscious or unconscious information needs. It consists of the actions, methods, and procedures to retrieve information from stored data. Information retrieval starts from the individual's information requirements, and then the individual selects one or more information sources based on their previous experience. In order to achieve successful retrieval in this source, the user needs to interact with the source by using indexing and search languages and communicating with the system through the human computer interface. It is necessary for the user to understand the use of the system through learning and training. Therefore, this level of information retrieval includes three main components: indexing and search languages, interfaces, and learning and cognitive framework.
- **Information Systems.** An information system is designed to enter, store and retrieve information. In order to support efficient and accurate data processing, information systems must be coupled with sufficient physical storage capacity and appropriate logical database structures. An information system consisting of hardware, software and communication networks is the invisible tool that supports

the information processing of individuals or organisations. Information systems have various categories, each of which serves the needs of different organisations or individuals.

- **Information Contexts.** The information context is the context in which information processing and management takes place. The context, including categories of organisation, businesses, education, home and the community, has a major influence on system design and encompasses the user. The context in which a specific information system operates determines the functions that the system can be expected to perform. By contrast, the ability of performing or recording transactions and the achievement of more flexible communication may change the context. This means that those opportunities offered by enhanced information systems have an influence on the way in which businesses operate, both on internal and external communications.
- **Information Environment.** The information environment surrounding information contexts contains the factors of political, legal, regulatory, societal, economic and technological forces. These are important in the information environment because factors which transcend national and international boundaries are elements of the information marketplace. The elements of the information marketplace include matters of pricing, intellectual property, international data transfer, social inclusion and exclusion, security and data protection, and archiving and bibliographic control, all of which are topical as the electronic information marketplace requires further developments.

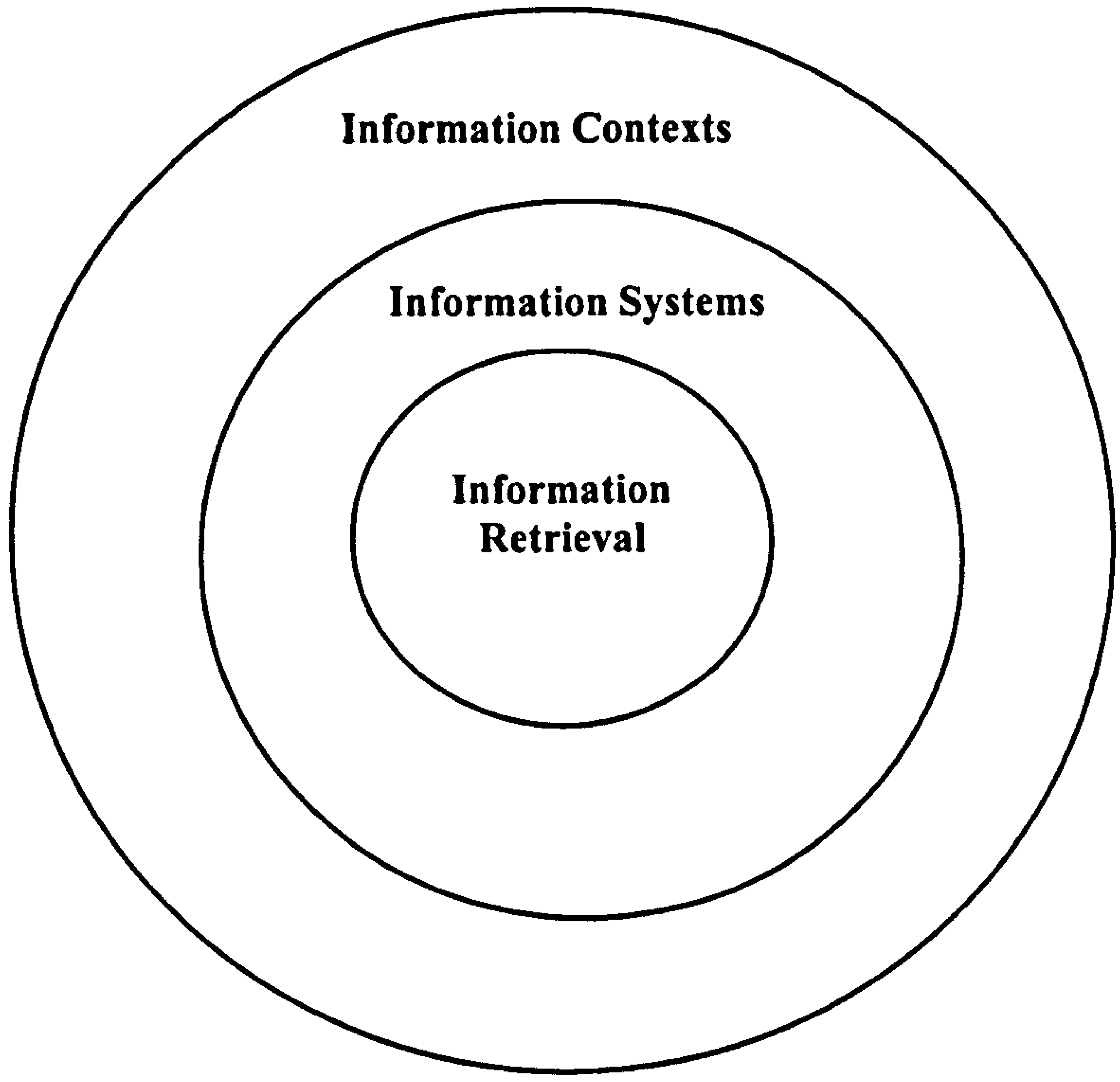


Figure 2. 1 A model for Information Management (Rowley, 1998)

These four levels can be broadly categorised into two sub-disciplines of information management: (i) micro-informatics that focuses on information retrieval and information systems, and (ii) macro-informatics that is concerned more broadly with the relationship between information and society and its organisations.

This information management model can be further developed to identify the information processing agent, information manager and the relationships between the levels and the various perspectives on the definition of information, see Table 2.1. In this table, information managers are information professionals and experts who act as agents on behalf of information processors to create and improve systems, so information processors are better able to meet their objectives.

Level	Information processing agent	Information managers	Information Definition
Information retrieval	Individual	Database designers, HCI designers, indexers, users	Information as subjective knowledge
Information systems	System	Systems analysts and designers	Information as data Information as thing
Information contexts	Organisation	Strategic information managers, strategic managers, organisational scientists	Information as a resource
Information environments	Society	Governments, multinational corporations, educational institutions	Information as a commodity Information as a constitutive force in society

Table 2. 1 Levels of information processing and management (Rowley, 1998)

Table 2.1 also provides an important link between the levels of information management and the differing perspectives on the definitional hierarchy of information. Rowley's model as the operational definition for 'information management' clearly shows that the different levels of information management and the definitional hierarchy of information are closely integrated.

2.3 CONSTRUCTION INFORMATION AND CONSTRUCTION INFORMATION MANAGEMENT

Before investigating the application of mobile computing for construction information management, it is essential to identify construction information and to explore the mechanisms of construction personnel retrieving, processing, transferring, communicating and managing information. This section intends to present an overview of construction information and construction information management with the emphasis on construction site information and construction site information management, which are the potential areas for applying mobile computing technology.

2.3.1 CONSTRUCTION INFORMATION AND MANAGEMENT IN HIERARCHY

In previous sections, the theoretical concept of information and information management has been concerned with differences at levels of scope and complexity. According to the operational definitions of information and information management, construction information and information management can be viewed from different perspectives and at various levels.

The first level of definitional hierarchy for information management is the information retrieval level that concerns the interaction between systems and individuals. The concept of information at this level is defined as subjective knowledge. Therefore, the information needs of construction personnel are linked with their managerial responsibilities. Construction information needed and retrieved by individuals can be viewed as the representation of knowledge. At this level, example construction information that is retrieved by individuals to support their information needs includes drawings, progress information, production schedules, safety regulations, and quality control. Starting from their information needs, construction individuals select one or more information sources that include paper-based or digital construction information storages based on their previous experience, and then use indexing and search languages with the communication to those sources through human computer interface. Construction information, as the represented knowledge retrieved from sources, has a great influence on the decision making of construction personnel and enhances their ability to problem solve in their workplace. The information processing agent at this level is the construction individual.

The second level of information management is the information system that is designed to enter, store and retrieve information. At this level, information is defined as data or thing. Construction information at this level can be considered as data that are performed and processed by various construction information management systems. Although an individual or an organisation can be regarded as an information system, the conventional use of the term information system refers to information technologies in terms of hardware, software and networks. Construction information systems coupled with sufficient physical storage capacity and logical database structures are the tools that support efficient and accurate information processing for construction individuals and construction organisations. Construction information systems have various categories, each of which serves the specific needs of construction individuals or organisations. Some examples include electronic construction document systems, knowledge management systems and Web-based project management systems.

The third level of information is the information context in which information processing and management take place. Construction information at this level can be described as a resource, such as technical information, commercial information and management information. The context in which a construction management information system operates determines the functions that the system can be expected to perform. On the other hand, the ability of information systems to perform more flexible and complex communication may change the context such that the functions that need to be performed change. Therefore, those opportunities offered by enhanced construction information systems have an influence on the way in which construction processes operate and are impacting both on internal communication and communication with construction suppliers and customers. According to the variety of construction information systems, construction information contexts can be defined into different types, such as the construction project respecting to project management systems and the construction company corresponding to organisational information systems.

2.3.2 CONSTRUCTION INFORMATION

2.3.2.1 Construction Organisational Information

There are many researchers who attempt to identify and categorise construction information from a general level division to a more detailed level or from a macro-perspective such as the organisational level to a micro-perspective such as the construction individual level.

From a macro-perspective, construction information can be grouped into three categories: general information, organisation-specific information, and project-specific information (Dawood et al., 2002):

- **General Information.** General information defines publicly or commercially available information including construction products, regulations, standard procedures, etc. This kind of information is generally available to other interested organisations.
- **Organisation-specific Information.** Organization-specific information concerns all information available to a specific organisation such as standard solutions to design-construction problems. It uses previous completed projects as reference cases to support decision making.

- **Project-specific information.** Project-specific information refers to a particular construction project, and is shared by different participants who are involved within this project.

At the organisational level, construction information can be classified into three categories: technical information, commercial information, and management and control information (BT, 1995):

- **Technical Information.** Technical information includes specific technical data and has relationships with clients, designers, project managers and suppliers. The technical information category concerns designs and technical details that describe a building. It includes drawings, specifications, details, and design clarifications.
- **Commercial Information.** Commercial information includes the contract details, which establish responsibilities for the delivery of a project, delivery schedules, costs, prices, payment schedules, terms and conditions.
- **Management and Control Information.** Management and control information is the project management information that is needed to control the project and generate reports. This information category developed by the project manager compose meeting minutes, submittals and shop drawings, change order status log, as-built drawing, requests for information, contract status log, safety information, daily logs and project schedules.

2.3.2.2 Construction Document

A document is the representation of information in a structured way or a unit of recorded information structured for human consumption (Gyampoh-Vidogah et al., 2003). Construction information is normally contained in various construction documents. In order to identify construction information in the organisational context, it might be useful to categorise documents existing in construction organisations and analyse each type of document to identify the construction information it contains.

Engineering documents can be classified into two types: item document and compound document (Sargent, 1993).

- **Item Document.** The item document is an individual piece of information that is managed as a single unit, and its contents are fixed when it comes into existence and never change. It is filed and archived with a unique reference number which never changes. Some examples include letters, orders, engineering drawings and contracts.
- **Compound Document.** The compound document is a collection of information from several sources, which appears to be a single document to the reader when it is printed and bound as a single report. It is created from many items and updated semi-automatically by other people who revise the items in the organisation. The compound document is merely a snapshot of the current status of some sets of information. Some examples of compound documents include progress reports, change notices, field reports, and failure notices.

After a questionnaire survey and additional interviews to construction contractors, Tenah (1984) classified construction reports into five groups: summary and narrative reports, schedule reports, cost reports, financial reports, and forecast and trend reports.

- **Summary and Narrative Reports.** These reports that basically go to construction management levels cover at least one of the following areas: schedule, cost, finance, and forecast and trend. These reports are normally prepared manually. Some examples of the summary and narrative reports include the board's summary report, president's narrative report, procurement directors narrative report, etc.

- **Schedule Reports.** Schedule reports are used by the appropriate engineering, construction, and project personnel to plan their work and monitor progresses. They are usually prepared either manually or by computer from precedence or other networks. Examples contain the master schedule and master network, engineering summary and detail schedules, procurement schedule report, construction weekly work plans, schedule report by total float, etc.
- **Cost Reports.** Cost reports provide the project personnel with necessary information to monitor and control the project budget, forecast, cost, and commitments. They are usually consistent and in a format for convenient comparison. Reports include the project summary cost status report, detailed cost estimate report, original/current project budget report, direct material cost and commitments by purchase.
- **Financial Reports.** Financial reports are produced from reassembling the basic information from invoices, change orders, contracts, allotment of funds, budgets, etc. The major purposes of financial reports are to help the planning and control of major project financial concerns, and to serve as a basic accounting tool and audit trail. Some examples include the multi-phase financial status report, programmed and actual contract cost reports, project file report, project payment report, project accounts report, etc.
- **Forecast and trend reports.** Forecast and trend reports provide the project team with such facts including the labour, man-hours, cost, material and schedule forecasts, labour performance evaluation and control, and deviations in project scope, cost, and schedule. This kind of report includes the project performance

report, performance summary report, quantity and unit rate report, detailed analysis report, man-hours summary report, quantity forecast report, etc.

During the construction process, various construction documents are generated. Typical documents contain submittals (shop drawings, text reports, and manufacturer data), correspondences, requests for information, change orders, and inspection reports. Researching project documentation on the arbitration process, Kangari (1995) presented results from a survey questionnaire collected from arbitrators. The finding results outlined recommendations made by those arbitrators. His findings (Kangari, 1995) summarised the following documents that have a major influence on the arbitration process:

- Detailed daily reports that outline workforce levels, trade reports, job progress, work descriptions, inspections, equipment used, material deliveries, weather, unusual conditions, and other factors.
- Jobsite log that should be maintained at site and faxed to head office every day.
- Progress photos that should be taken weekly and dated, signed, and filed.
- The personal daily diary maintained by project manager.
- Chronological files of all job activities including delivery tickets, field orders, change orders, and payment requisitions.
- Weekly meeting minutes that should be maintained and stored in the home office.
- Transmittal records that are stored at the head office.
- Requests for information, change orders, fields directions, which should be stored at head office.

2.3.2.3 The Utilised Information in the Construction Process

The construction process can be represented in four stages: project conception, design of facility, construction of facility and use of facility, which is illustrated in Figure 2.2 (Kamara, 1999). During the project design stage, professionals design all aspects of the facility and develop a set of design drawings (the output) that are converted into the construction stage. At the construction stage, the design is transformed into a facility for the use of the client.

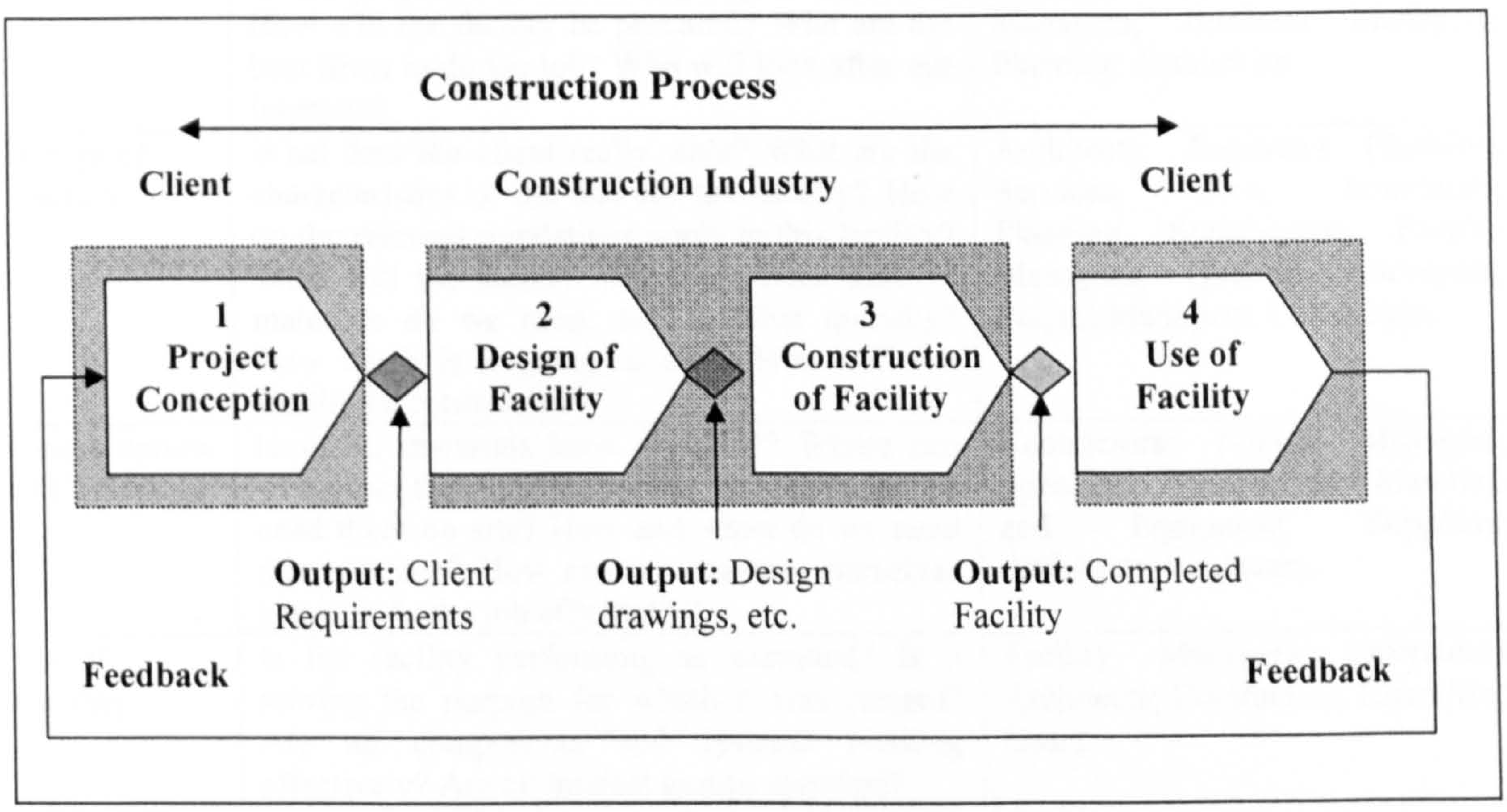


Figure 2. 2 A simplified model of the construction process (Kamara, 1999)

The construction process requires vast amounts of information and each stage has differing information needs. Information required by construction processes include the nature and wishes of the client (client requirements), the nature and desires of proposed users of the facility (user requirements), the nature of the site on which the facility is to be built and the immediate environment (site information), and information on the regulations that apply to that facility. The whole process involves the collection, processing and management of information to enable the erection of a facility that will satisfy the client. The collection and processing of information is concentrated in the conception and design phases. The construction stage deals with the implementation of the design. During the use and operation, the facility is evaluated against the requirements defined in the planning stage. Information required and managed with respect to the different stages in the construction process and the professionals involved, is summarised in Table 2.2 (Kamara, 1999).

Activity	Information Collected	Professionals Involved
Project Conception	Do we need a project? What purpose will the facility serve? How much funds can we commit to the project? Where is it going to be built? How will the facility be procured? Who are the best firms to do the job? Who will look after our interests?	Development Managers; Property Consultants; Project Managers; Financial Consultants; Facility Managers, Business Managers; Planning Authorities.
Design of Facility	What does the client really want? What are the characteristics of the site for the facility? How do the relevant regulations apply to this facility? What will the facility look like? What kind of materials do we need, and in what quantity? How much is it going to cost? How will the facility be constructed?	Architects; Engineers (Building Services, Civil, Structural); Planning Supervisors; Facility Managers; Quantity Surveyors; Project Managers; Contractors.
Construction of Facility	Have all materials been specified? Where can we obtain the materials? How and when do we need them on site? How and when do we need them on site? How can we organise ourselves better to do the job efficiently?	Contractors; Project Managers; Specialist Contractors; Materials and Equipment Suppliers; Architects, Engineers.
Use of Facility	Is the facility performing as expected? Is it serving the purpose for which it was created? Are all components and systems working effectively? Are all interest groups satisfied?	Facility Managers (operators); Architects; Contractors; Client/End Users.

Table 2. 2 Kind of information & the professionals involved in the construction process (Kamara, 1999)

2.3.2.4 Construction Site Information

According to de la Garza and Howitt (1998), construction site information is organised into ten major categories: RFI (Request For Information), materials management, equipment management, cost management, schedule and means and methods, jobsite record keeping, submittals, safety, QC/QA, and future trends. Each of the major categories are further divided into information subcategories in greater detail, see Table 2.3.

Request for information	Materials management	Equipment management	Cost management	Schedule and means and methods	Jobsite record keeping	Submittals	Safety	QC/QA	Future trends
Design intent and clarification	Access to material management	Equipment location	Budget	Schedule updates	Recording timesheets	Test results	Accident reporting	Initiate inspections	Positioning data
Subcontractor information	Material location	Fuel monitoring	Material cost accounting	Delay recording	Progress reporting	Revisions to submittals	Reporting violations	Report QC/QA problems	Sensory data
Contract specifications	Material order status		Equipment cost accounting	As-built records	Exception reporting			Report inspection results	
Contract drawings	Request materials to site			Productivity information	Visitor's log				
Work package information	Place material orders								
Means and methods									
Implementation problems									

Table 2. 3 Construction site information (de la Garza and Howitt, 1998)

Site records consist of a range of information relating to construction processes and exist in a range of different forms such as minutes, correspondence, file notes, materials delivery invoices, photographs, personal diaries etc. These records provide efficient information to higher level management to monitor and control construction processes and solve construction conflicts and disputes. Scott and Assadi (1999) identified and grouped construction site records into three major categories: financial records, quality records and progress records.

- **Financial Records.** Financial records includes all measurements of work quantities with agreed rates, which allow contractors to obtain proper payments.
- **Quality Records.** The quality related records are composed of the results of tests conducted on the materials used and on the standard of workmanship.
- **Progress Records.** Progress records are always maintained by construction site supervisors and are the most important information that aims to identify the works carried out during the project life-cycle. This type of record that includes information relating to construction activities, job starting time, resources used and any disruption and delay, would be personal diaries, site diaries, minutes of progress meetings, day-work sheets, photographs, as-built programmes/schedules, and weekly progress reports.

2.3.2.5 Construction Personnel and Their Information Needs

In addition to the information needs on construction sites, different construction personnel also have specific information needs. Tenah (1986) carried out his research focusing on this area and looked at the responsibilities and the information needs of key construction personnel from the chairman of the board of directors to the foreman in the organisation. His study found a wide array of functions within construction organisations and revealed that information needs are often inextricably linked to the management responsibilities of each member of the project team. Table 2.4 gives an example of a foreman's management responsibilities and information needs.

Primary functions	Primary information needs
• 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.	• 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.

Table 2. 4 Forman's management responsibilities and their information needs (Tenah, 1986)

By using the matrix model approach, Shahid and Froese (1998) identified the various construction personnel along with their roles, functions, information needs and the documents that contain the information required by them. Table 2.5, as part of the personnel versus information needs matrix, shows an example of the relationships between personnel and their information needs.

PERSONNEL Vs. INFORMATION NEEDS MATRIX														
Infoneed / Information Needs	Construction Mgr	Chief Engineer	Procurement Mgr	Project Manager	Project Engineer	Planning/Sched.	Cost Engineer	Estimatio/QS	Accountant	Purchasing Agent	Field Office Enginee	Field Engineer	Superintendents	Foremen
Procurement														
Suppliers directory			X							X				
Requirement dates of materials			X	X						X			X	
Sample/approval requirements			X	X	X					X	X			
Approval time for submittals			X	X	X					X	X			
Delivery time of materials			X	X	X					X				
Materials affected by change orders			X							X			X	
Status of materials on job site				X		X		X				X	X	
Quantity of materials required				X						X		X	X	
Quantity of materials stored				X				X					X	
Supplier of materials			X						X					
Lists of spare parts required			X	X						X				
Details of spare parts			X	X						X				
Quantity of spare parts required & delivered			X	X						X				
Quantity of spare parts balance			X	X						X				
Location of spare parts stored										X			X	
Supplier of spare parts			X							X				
Project Management														
Daily work progress				X	X								X	X
Equipment in use and idle on job site				X			X		X			X	X	X
Daily labour force on job site				X			X		X				X	X
Daily weather condition				X										
Visitors on job site				X	X							X	X	
Materials requirements														
Lists of site photograph				X	X									
Negative/roll number of photograph				X	X									
Date and location of photograph				X	X									
Purpose of photograph				X	X									
Site Management														
Lists of defective work notice (DWN)				X	X						X		X	
Details of defective work notice				X	X						X		X	
Subcontractor responsible for DWN				X	X						X		X	
Value of DWN				X				X						
Punch lists and details item lists				X	X						X		X	
Subcontractor responsible for punch list				X	X						X		X	
Status of punch lists				X	X						X		X	
Administrative														
Owners contact & phone	X			X										
Architects/engineers contact & phone	X	X		X	X						X			
Subcontractors contact & phone				X	X			X	X		X		X	
Suppliers contact & phone			X	X	X		X			X	X		X	
Correspondence in & out list	X	X	X	X	X	X	X	X	X	X	X			
Contents of a correspondence	X	X	X	X	X	X	X	X	X	X	X			
Origins of correspondence	X	X	X	X	X	X	X	X	X	X	X			
Dates of correspondence	X	X	X	X	X	X	X	X	X	X	X			
File-location of correspondence	X	X	X	X	X	X	X		X	X	X			

Table 2. 5 Personnel vs. information needs matrix (Shahid and Froese, 1998)

2.3.2.6 The Need for Construction Information Management

From the discussion in Section 2.3.1 regarding the construction information from different perspectives, it is clear that the construction industry is an information intensive environment from design offices to project construction sites. Because of the intensity and diversity of construction information, the efficiency of information management is crucial to the construction industry and has been recognised as an important competitive advantage to construction companies.

Research (Dawood et al., 2002; Gyampoh-Vidogah et al., 2003; Mead, 2001; Rezgui, 2001) has shown that the accurate and efficient management of construction information is one of the keys to achieving successful construction projects. One important (CII 1997) study by the Construction Industry Institute pointed out that there exists a need to identify, compile, and accurately transfer relevant information among team members throughout the entire life-cycle of a project, and then project performance can be enhanced through the implementation of effective project information management, as a project can fail if hindered by poor information management.

Other research (IAI, 2002; O'Conner and Tucker, 1986) focusing on the construction industry suggested that one of the major factors of inefficiency in a construction project is the problems arising from the transmission of construction information. As an example, 22.1% of the problems occurring on a construction site relate to the communication of design information (O'Conner and Tucker, 1986), and it has also been estimated that up to 30% of the cost of a building project is due to the fractured processes and communication of the AEC/FM industry (IAI, 2002). In general, inefficient information management often causes delays, additional costs and consequently damages relationships with customers.

As construction information covers many aspects, from the objectives through the strategies, planning and control, to detailed operations of the organisation, construction individuals at the various management levels need to manage massive volumes of information for proper decision making. Effective information management enables managerial individuals at different levels to have a better understanding of what is happening and to make better decisions for the project (Tenah, 1984).

Therefore, construction information management is the key factor to successful construction performance at both the organisational level and the individual level. The extensive review of current information management in the construction industry is discussed in the following sections.

2.3.3 CONSTRUCTION INFORMATION MANAGEMENT

2.3.3.1 Construction Information Management Practices

Research in this area have developed and practiced a number of approaches, practices and technologies for the management of construction information. These research issues include:

Modelling Approach for Information Flow

With the development of the construction industry, information transfers between participating organisations and internally among the personnel within organizations have become more and more critical. Methodologies developed by the software industry from the system analysis and design purposes have proved valuable in the study of information flow within construction organisations.

The modelling method of Data Flow Diagrams (DFDs), which focuses on information exchange between activities, has been widely used to map the information flow in a system for recording its transformation and coordination. Some examples include the research of Fisher and Yin (1992) who described a General Data Flow Model (GDFM) focusing on project construction stage and the research (Baldwing et al., 1999) that simulated the information flow at the conceptual and schematic stages of building design.

Construction Document Management

In the construction industry, information management problems are always concerned as the same as document management or include document management. Since document is one of the best ways for communicating or creating information, issues of improving capabilities of managing vast amount of information transmissions cannot be discussed without addressing problems of the document management.

The document management approach that builds on current documentation practices is to enhance document management through the widespread adoption of electronic document management systems within companies and across all the participants in projects. Joia (1998) indicated current document management including the following problems:

- On average, only 5% of a company's documentation is on-line together with 5% in digital media or microfiche: 90% is on paper.
- Employees in a company waste up to 8 hours per week on average looking for information because of lost or misplaced documents.
- Information is always outdated.
- Engineers spend more time looking for information rather than using it.
- Documents are always created from scratch, as it is very difficult to find a useful template.
- It is barely possible to create documents with the collaboration of partners, because of no process to achieve a workgroup environment.
- Engineers possibly work on an outdated version of an engineering document because of the difficulty in finding the most recent version.

Because of the importance of document management, the challenge that the industry is facing today is the reuse of the knowledge and information stored within these documents (Rezgui, 2001). Rezgui's research summarised the limitations of existing proprietary Electronic Document Management (EDM) systems in the construction industry:

- Every participant within the project must use the same EDM system on a project in order to access and share documents.
- The EDM system does not control the semantics and internal structuring of documents.
- The EDM system does not support document cross-referencing or semantic linking.
- The security of the EDM system needs to be improved.
- The EDM system is not integrated with proprietary and commercial applications.

- EDM systems lacking user-friendliness, or used in a maladapted environment, discourage users from using the system.

Research projects that aim to tackle the above problems include RATAS (Björk, 1993), ATLAS (Bohms et al., 1994), DOCCIME (Rezgui and Debras, 1996) and CONDOR (Rezgui and Zarli, 2001). In addition, many commercial web-based EDM systems, which include Project Net, BidCom, Evolv, and Buzzsaw, can provide document and workflow management services across the Internet.

Product Modelling

Because of the fragmentation that leads to low efficiency of information communication and the difficulty of information sharing, there is a need for the integration of construction information across various disciplines in the construction industry. Product modelling is an important step towards the integration of information and aims to deal with the transfer of engineering information between computer systems and between users of those systems.

In order to improve the effective sharing of integrated construction project information, the following issues should be properly addressed (Rezgui, 2001):

- support for the behavioural aspects of products;
- support for flexible-form models;
- support for different views by different actors;
- the life-cycle positioning and functional objectives of application protocols;
- support for object states, versioning and ownership; and
- support for project history and intent behind decision.

The early efforts of product modelling in the construction industry include DXF (NEDO, 1989), IGES (IGES, 1991) and EDI (EDICON, 1991). Since the first version of STEP (Standard for the Exchange of Product Model Data) was published by ISO (International Standards Organization) as a draft international standard in 1993 (ISO, 1993), STEP standards have continued to grow and evolve for many years. Following the STEP standards, there are a number of construction-related product modelling research projects including CIMsteel project (CIMsteel, 1993), COMBINE project (Augenbroe, 1995), ATLAS (Greening and Edwards, 1995) and Building Elements Using Explicit Shape Representation (Part 225) (ISO, N.D.-a). Additionally, some research projects in this area try to solve problems for the absence of an overall STEP modelling framework for construction such as RATAS project (Björk, 1994), BCCM (Building Construction Core Model) (Part 106) (ISO, N.D.-b), GARM (General AEC Reference Model) (Gielingh, 1988) and IFC (Industry Foundation Classes) (IAI, 1997).

Groupware System

The research area of Computer Support for Cooperative Work (CSCW) is mainly concerned with the application of the Groupware System to support teamwork. The Groupware System is designed to deal with highly unstructured data, including text, images, graphics, faxes, mail and bulletin boards, with a subset of system components such as workflow (task scheduling), multimedia document management, email, conferencing and shared scheduling of appointments. The advantages of using Groupware Systems include the efficient management and tracking of project lifecycles, collaboration on specific tasks among project participants, and the reuse of previous knowledge.

As an example, the OSMOS project (Marache et al., 2001) that aims to enhance the capabilities of construction enterprises to collaborate effectively on projects has used the existing standards including CORBA services, the XML DOM standard object API, the Workflow Client API from the Workflow Management Coalition, mail APIs, and Calendaring and Scheduling API from XAPIA standards association.

Knowledge Management System

There are two main types of knowledge management systems: the knowledge-based system and case-based reasoning. Knowledge-based systems have been undertaken and deployed in the construction industry to deal with problems that had an explicit model-based representation implemented through rules or objects (Watson and Marir, 1994). Because of the problematic nature of knowledge-based systems that require explicit problem-domain model, case-based reasoning has been developed to organise the structured archival of past experiences for future potential reuses. These experiences referring to cases are archived along with their unique domain characteristics expressed through well-defined indexes that describe the essence of the case (Watson and Marir, 1994).

Most available knowledge-management systems including knowledge-based system and case-based reasoning rely on users' inputs to explore and retrieve information or knowledge. It leads to the increasingly complex development of IT systems and the limited collaborative functionality (Berney and Ferneley, 1999). Prior to the application of the technology to facilitate collaboration, an appropriate organisational culture must be in place to make use of the technology effectively, which is an area where the agent technology can provide potential solutions (Skyrme, 1999).

Web-based Project Management System

The use of Information Technology in improving coordination and collaboration between project participants can lead to better communication practices. The application of Internet and World Wide Web will be the key to change in the global construction business and influence communications, collaborations and business structures in the construction industry (Walker and Songer, 1997). The advantages of Web technologies in construction can be broadly categorised into three areas: the support of relevant information services, communications between project participants and engineering and management computing. The concept of how Web technologies can be applied to manage construction projects is often referred to as a Web-based Project Management System (WPMS) that enhances the construction project documentation and control by revolutionising the way the construction project team conducts business (Walker and Songer, 1997).

Mead (1997) summarised that there are four general categories of construction project information including project information, design information, management information and financial information, which are normally conducted by Web-based Project Management Systems (WPMS). Nitithamyong and Skibniewski (2004) revealed three types of strategy for the implementation of Web-based Project Management Systems (WPMS). These strategies include the development of customised WPMS by hiring the consulting company or programme professionals, the development of WPMS by purchasing commercial web-enabled packaged software, and finally the rent of completely developed WPMS from an Application Service Provider (ASP) for a usage fee.

2.3.3.2 Existing Problems of Construction Information Management

Many researchers have investigated the existing problems for information management in the construction industry. For example, the communication methods between project participants were inefficient (Latham, 1994), and small or medium sized contractors suffer from the result of poor information exchange and control systems (Kangari, 1995). In addition, information provided during the contract process is almost always incomplete, which leads to long tending and results in inaccurate cost estimation (Finch et al., 1996a). The reason for the inefficient progress in the area of project management is often not well understood, because the existing models of the design process are inadequate if a detailed understanding of information-related events is to be obtained (Baldwin et al., 1999), and because the industry has focused on general quality management although clients are more concerned with information providing and exchanging (Laitinen, 1998). Moreover, Newcombe and Landford (1990) expressed the view that the primary tasks of all organisations are affected by the internal culture of the business, but the challenge is how to reconcile the human, organisational and technical factors when managing information systems.

From the review of information management practices in the construction industry, Gyampoh-Vidogah et al. (2003) characterised and specified the current state of construction information management by systems in which:

- paper is the major medium for information exchange among project participants and leads to slow and inefficient information retrievals and searching;
- functional departments maintain their own data structured to suit their particular needs;

- most information searching and transfer between project participants are paper based, which provide a constant source of delays;
- no efficient interfaces exist between departmental systems to access information electronically; and
- the impact of IT investment to data has been limited.

Additionally, the research survey (Zarli and Richaud, 1999) revealed the following limitations of current technology solutions to resolve information management problems in the construction industry:

- **Homogeneity.** Although recent evolutions of information technologies have great opportunities, existing solutions are still often fixed and not open to upcoming new systems and technologies.
- **High entry level.** IT solutions are still often expensive to buy and more entry levels should be provided.
- **Lack of scalability.** Most available proprietary and commercial solutions offer a limited growth path in terms of hardware and software.
- **Application-centric and lacking support for business processes.** There is often a requirement to organise the enterprise around the adopted IT solution.

The key reasons for those limitations are identified and clarified by Rezgui (2001) as follows:

- Much construction knowledge resides in the minds of the individuals working within the domain.

- It is difficult to record or document the intent behind decisions because of the complex processes needed to track and record the huge number of messages, phone calls, and conversations.
- Misunderstandings of information specific needs exist for people who are responsible for collecting and archiving project data.
- The data is usually not managed while it is created but is instead captured and archived at the end of the construction stage.
- Lessons learned are not well organised and are buried in detail. It is difficult to compile and disseminate useful knowledge to other projects.

All of the identified problems indicate that solutions to construction information management problems are not simple and straightforward, and are involved in all organisational levels ranging from strategic to operational level and all functional areas including marketing, finance, design, and construction. Therefore, any practice targeted at solving information management problems should be concerned with both hard issues including the technology and re-engineering and soft issues such as culture and education.

2.3.3.3 The Need for Integrated Design and Construction

In the construction industry, each construction project involves a number of participants collaborating for a relatively short period in the development of the required facility. The traditional approach to construction procurement applies a sequential approach to project development, with the architects completing most of their designs before the structural engineers, who in turn complete theirs before the construction phase. The involvement of various professionals and the traditional procurement process has resulted in the clear separation between the design and construction organisations involved in the project and a clear separation between the design and construction phases of the building process. This organisational and sequential separation has come at a price, frequently resulting in construction schedule delays, cost overruns, increased litigation, and poor building quality (de la Garza, 1994).

When the separation between design and production was found in the manufacturing industry, the strategy of "concurrent engineering" was adopted by the industry. With the application of concurrent engineering, multidisciplinary teams can perform design and production tasks concurrently resulting in an improvement in productivity between design and production, benefits to cost savings, the match of customers' needs, and increased product quality (Evbuomwan and Anumba, 1996; Prasad, 1996; Smith et al., 1995). The success of concurrent engineering in the manufacturing industry has led to a motivation for its application to the construction industry (Anumba et al., 1997; Anumba and Evbuomwan, 1995; de la Garza, 1994; Kamara et al., 1997). However, the application of concurrent engineering in the construction industry has to confront the key difference between manufacturing and construction. In the manufacturing industry, the production environment is tightly controlled in factories, and design and production personnel are likely to be collocated at the same plant. In the construction industry, the production environment (construction work site) is outdoors and far from the offices of designers. This key difference has a great impact on the success of concurrent engineering in the construction industry, because information communication between design teams and construction contractors is the key challenge to the implementation of concurrent engineering (Fergusson, 1993). The production point (construction work site), an outdoor environment and far from design offices, has led to the difficulty of information communication between design teams and construction contractors, and the difficulty of project information access by project participants on construction work sites.

Design and construction are different stages in the construction process. Design is the link between client requirements and the actual realisation of those requirements into a constructed facility. At the design stage, the inputs of client requirements are translated into information for actual construction. In order to satisfy client's needs and ensure that the design is constructable, the design stage must not only have the client's requirements as input, but also information about construction and the operation and maintenance of the facility (Kamara et al., 1996). Therefore, the design stage must be integrated with information about construction and use (life cycle considerations), see Figure 2.3. The integrated design and construction then represents a stage in the integration process and a clear response to evolving customer demands.

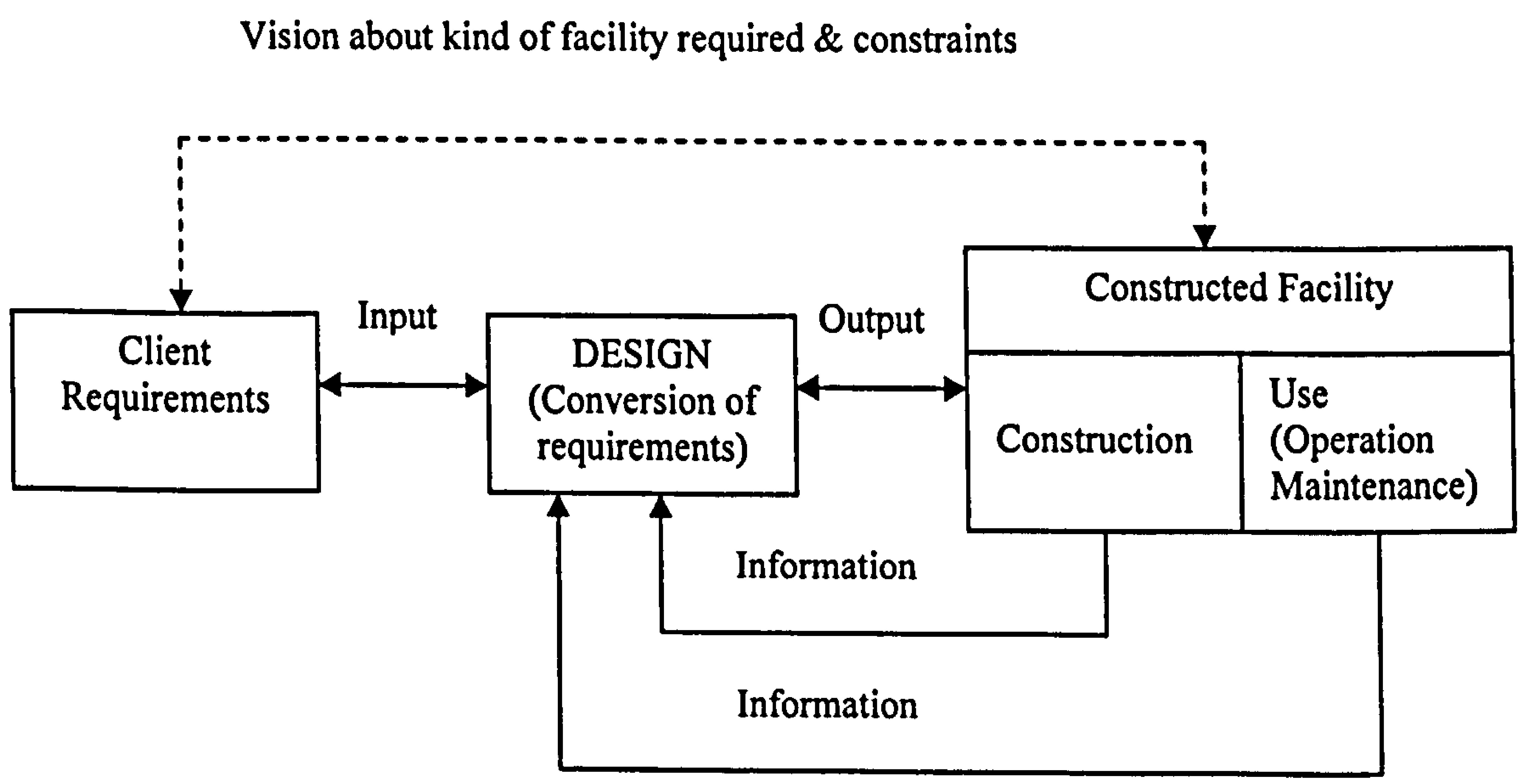


Figure 2. 3 Integration of construction & life cycle information into design (Kamara et al., 1996)

The principles of integrated design and construction require effective communication at the task level between the work point and the design team. Because current information communication methods prevent effective information access at construction work sites, project-level reengineering of the building process cannot improve the deficiency of communication between the construction and the design. Waiting for design information is recognised to be the principal cause of delays in on-site construction work; therefore, this problem must be solved on the construction work sites. Only when this task-level bottleneck of information communication is resolved can the benefits of applying concurrent engineering in the construction industry be achieved at a larger scale (Elvin, 2003).

However, the construction industry has not found appropriate solutions for the problem of information communication and exchange on construction work sites. According to the discussion in Section 2.3.2.4, construction sites are information intensive environments. Various construction personnel in the field need large amounts of information ranging from project design drawings to personal diaries to support their ongoing work and for their decision making. However, the main type of information that on-site construction personnel receive and transfer is paper-based files, which include documents such as drawings, data collection forms, correspondences, progress information and specifications (Bowden et al., 2004). The limitation of paper-based files has remained a major constraint in on-site information communication and exchange. Ineffective on-site information communication can result in construction personnel overlooking important issues that require a quick response and often cause on-site decisions to be deferred (Singhvi and Terk, 2003). Coordination of activities and management of operations on a construction site raises numerous queries and interactions between project participants, which need to be resolved quickly and efficiently to avoid downtime, rework, waste and cost overruns (Miah et al., 1998).

The development of Information Technology gives the construction industry a powerful potential to increase the efficiency and effectiveness of information exchange, but current IT support has only extended to construction site offices and there are still gaps between site offices and actual work sites. The emergence of Mobile Computing (MC) has the potential to enlarge the boundary of information systems from site offices to actual work sites and ensure real time data flow to and from the construction work sites. Therefore, the potential of mobile computing can improve information communications between the fieldworkers at the point of work and off-site collaborators in building design, which is the key principle of integrated design and construction.

2.4 PROBLEM ANALYSIS

Information is an essential but intangible concept. The concept of "information" has been variously defined by early researchers in order to better understand how information is and might be processed and managed, see Section 2.1.1.1. However, Wellisch (1972) argued that these early definers of "information" did not succeed in arriving at an agreed-upon definition, nor did their definitions have any common elements. Because of the differences in level of scope (how broad a range of social phenomena is combined into the concept) and complexity (how variously articulated is the social organisation), the definition of "information" must take into account the differences in phenomena at different levels in the context structure. Therefore, the definitional hierarchy that provides the selection of definitions for use in particular situations has been widely adopted by researchers. The definitional hierarchy offers a variety of different perspectives which can be summarised as the following distinct definitions: information as a resource (Eaton and Bawden, 1999); information as a commodity (Choo, 1996); information as perception of pattern (Braman, 1989); information as data in the environment (McCreadie and Rice, 1999); information as representation of knowledge (Ingerwesen, 1996); information as part of a process of communication (McCreadie and Rice, 1999); and information as a constitutive force in society (Braman, 1989), see Section 2.2.1.2.

Because of the different perspectives on the nature of information, researchers from different disciplines contribute to the debate about the nature of information management based on their own experiences and purposes, see Section 2.2.2.1. However, Rowley (1998) argued that disciplinary definers cannot avoid the consideration of the processing of information when seeking to define the concept "information" and these different perspectives on the nature of information must be embedded in any definitional framework that seeks to understand the nature of information management. Therefore, she presented a framework that recognises the need to consider the different levels of the individual, the system, the context and the environment in information management, see Section 2.2.2.3.

The construction industry is an information-intensive industry since hundreds and thousands of pieces of information need to be transferred and exchanged during the life-cycle of project design and construction. The discussed information theories provide a possible way for identifying and analysing construction information and their management from different levels in order to provide an understanding of the nature of construction information management. At the individual level, construction needs of different construction individuals are often inextricably linked to their responsibilities in the project team (Tenah, 1986). Construction information that can be recognised as subjective knowledge at this level has a great influence on the decision making processes for different individuals and affects their ability to solve related problems. At the system level, there are many research efforts that focus on the design, development and practice of construction information management systems. These information systems include Electronic Document Management (EDM) systems (Joia, 1998; Rezgui, 2001; Rezgui and Zarli, 2001); Groupware Systems (Marache et al., 2001); Knowledge Management systems (Berney and Ferneley, 1999; Skyme, 1999) and Web-based Project Management systems (Mead, 1997; Nitithamyong and Skibniewski, 2004). At the organisational level, construction information can be seen as a resource and is identified as technical information, commercial information and management and control information (BT, 1995). The current state of information management at organisational level includes paper-based mediums for information exchanges, various data structures in different departments, paper-based information searching and transfer, inefficient interfaces between systems, and limited impact of IT investment (Gyampoh-Vidogah et al., 2003). Recommendations for the improvement of organisational information management include the development of information management policy within business strategies, changing cultural issues, process re-engineering and the reassessment of new systems and IT infrastructure (Gyampoh-Vidogah et al., 2003).

Information Technology has been widely applied at different information management levels in the construction industry. However, construction projects typically take place on construction sites where personnel have difficulty in gaining access to conventional computer systems. The characteristics of construction areas, such as irregular and open terrain undergoing frequent changes, and numerous pieces of heavy equipment moving around, prevent the use of conventional IT tools for on-site construction professionals (Meissner et al., 2001). Managers, engineers and other key personnel move frequently from site to site and from site offices to the sites. It is often inconvenient to carry bulky drawings and documents onto construction sites. There are three variables including quality, quantity, and timing of information, which can either hinder or facilitate the success of a project during the construction stage (de la Garza and Howitt, 1998). However, the main information transferred and exchanged on construction sites is paper-based files and the paper-based tasks that construction personnel carry out in their normal work are numerous (Bowden et al., 2004). Because current paper-based on-site construction processes are unable to deliver just-in-time information, the paper-based pipeline of information is clogged and creates an information deficit (de la Garza and Howitt, 1998). Ineffective information communication on construction sites can lead to the neglect of important issues that require a quick response, which may result in on-site decisions being deferred (Singhvi and Terk, 2003). The inefficiency of on-site queries and interactions between project participants may cause downtime, redoing work, waste and cost overruns (Miah et al., 1998). Only when the bottleneck of information communication on construction sites is resolved can integrated design and construction be achieved on a larger scale (Elvin, 2003).

Current IT support has extended to construction site offices, but the digital information flows are interrupted before reaching actual work sites. The emergence of Mobile Computing (MC) has the potential to enlarge the boundary of information systems from site offices to actual work sites and ensure real time data flow to and from construction work sites. The mobile computing technology is available, see Chapter 2, however, the development of communication and data exchange systems should meet the different requirements and views of the multiple professional disciplines involved in construction processes (Dawood, 2002). Therefore, the context in which construction personnel retrieve and transfer construction information should be investigated before the implementation of mobile computing on sites. The contexts that need to be understood include the type of work performed on work sites, the nature of the site environment, the type of information needed, and the spatial and mobility constraints (Garrett, 2000).

Research in the area of construction site information management includes the identification of on-site information (de la Garza and Howitt, 1998) and site records (Scott and Assadi, 1999); foreman's information needs (Tenah, 1986); the information flow on project construction stage (Fisher and Yin, 1992); and the information needs of a specific construction process (Bowden et al., 2004). However, current research only focuses on limited aspects or single facets and cannot provide a general context of on-site information management for the development of mobile computing systems. Therefore, in order to explore how mobile computing can be used to manage information on construction sites, this research conducts case study analysis and a survey to investigate the mechanisms of information communication on construction sites. The case studies and survey aim to provide an understanding of the general context in which mobile computing can be implemented to manage information.

2.5 SUMMARY

This section identified different types of construction information and reviewed technologies, practices and existing problems for current construction information management. The difficulty and inefficiency of information communication on construction work sites has still not been solved by the industry that required new IT tools for the integration of design and construction. The next chapter will introduce mobile computing technologies and their use in construction site information management.

CHAPTER 3

MOBILE COMPUTING

3.1 INTRODUCTION

This chapter introduces the concept of mobile computing, reviews current commercially available mobile computers, wireless networks and mobile applications, and finally discusses the mobile computing research in the construction industry. Outcomes of this literature review include the concept framework that integrates mobile computing with information management, and the scenario that illustrates possible ways of using mobile computing technologies in a particular construction situation.

3.2 THE DEVELOPMENT OF MOBILE COMPUTING

Since the mid 1970s, the concept of making the personal computer has changed the way people dealt with information, and taken a first step toward increasing the use of computers for more and more people. It also stimulated the phenomenal growth of hardware components and the development of software programming. However, the Personal Computer (PC) that has independent, separated and dispersive features cannot deliver the full potential benefits of IT to end-users. In order to increase the efficiency of information sharing, there are three major evolution steps: distributed computing, mobile computing and pervasive computing, each of which has identified and solved particular technological problems (Saha and Mukherjee, 2003).

Distributed computing surfaced with the advance of computer networking. The key values of connecting computers together are the capabilities that computers can access and share remote information resources over networks and the communication among independent users. Saha and Mukherjee (2003) pointed out one of the most important networking technologies is the World Wide Web which was not designed to be an infrastructure of distributed computing but it has experimented its concept. The practice of Web technologies has demonstrated that dispersive information resources can be integrated into a single structure with simple mechanisms and that computing capabilities can be shared without losing scalability. From the mid 1970s through to the early 1990s, research on the domain of distributed computing has become mature with the creation of conceptual frameworks and algorithmic bases. Satyanarayanan (2001) has summarised the key research areas of distributed computing, such as remote communication, fault tolerance, high availability, remote information access and security, and indicated this body of knowledge is now well codified in textbooks.

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

In 1991, an inspired vision of computing originated with Weiser (1991), who said "*The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*" This vision is the basis of the concept of ubiquitous computing, now also called pervasive computing, which implied a new way of thinking about computers and the new relationships between computers and users. The goal of pervasive computing explained by Weiser (1993) is to enhance computer use by integrating many computers into the physical environment, but making them "disappear" to the user. This suggests that pervasive computing is more environment-centric, and the interactions of users and computer systems are not constrained by current I/O devices (e.g. monitor, keyboard or mouse), but rather are extended to the physical environment around users. What makes pervasive computing different from other traditional computing is the need for perceptual information about the environment.

Although Weiser's vision was far ahead of its time and the required hardware did not exist, many essential elements of pervasive computing are now available and have become commercial products such as handheld and wearable computers, high bandwidth wireless networks, sensors and new programming technologies. Saha and Mukherjee (2003) compared the goals of pervasive computing and mobile computing, and then indicated that pervasive computing is a superset of mobile computing. In addition to the goal of mobile computing, which is recognised as "anytime anywhere", a reactive approach to access information, pervasive computing aims to achieve "all the time everywhere", which is the pro-activity concept that users can have seamless access to computing whenever they need it. The basic elements of pervasive computing include devices, networking, middleware, and applications. Figure 3.1 is the framework that illustrates their relationships and explains their functions (Saha and Mukherjee, 2003).

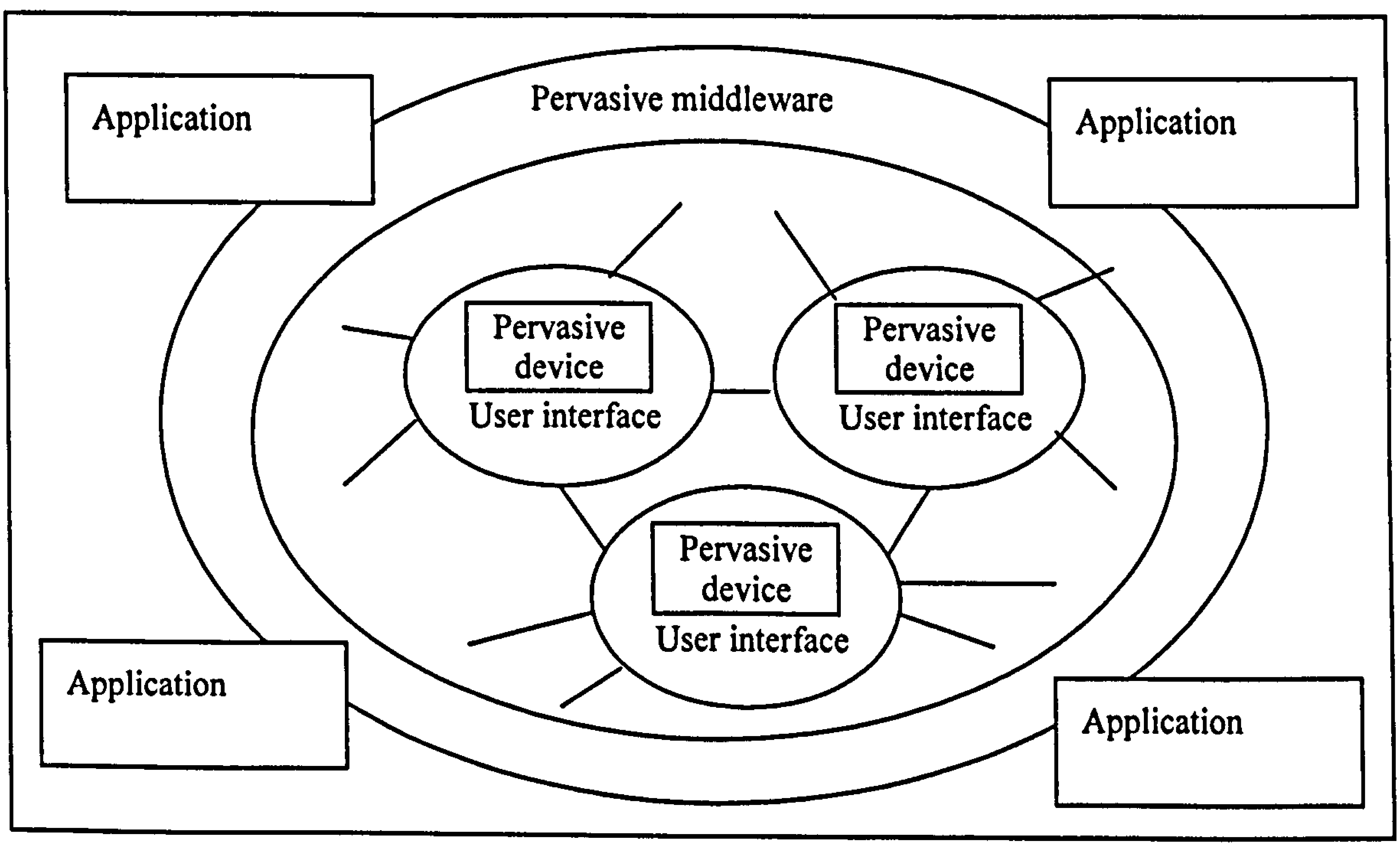


Figure 3. 1 Pervasive computing framework (Saha and Mukherjee, 2003)

3.3 THE CONCEPT OF MOBILE COMPUTING

Before the discussion of applying mobile computing in on-site construction information management, it is necessary to explain what exactly is meant by mobile computing. The concept of Mobile Computing (MC) has been considered to consist of three major components: mobile computer, wireless network and mobile application (Rebolj and Menzel, 2004).

The mobile computer that can be used indoors and outdoors by users while the user is in motion includes tablet PCs, all kinds of pocket computers, palmtops, and wearable computers. These kinds of computers have different accessories such as sensors, RFID (Radio Frequency Identification), and laser distance measuring devices. However, the mobile computer excludes conventional notebooks because the general use of notebooks is fixed in offices as desktop computers. Mobile computers are self-contained electronic devices that are easy to carry, and have enough processing power with an independent centre processor, memory, and input/output equipment. They can run application software that supports the functions used by users for their daily work.

The wireless network can support the connection and communication of mobile computers with sufficient bandwidth and can be accessed while mobile computers are in motion. Wireless networks include Wireless Wide Area Network (WWAN), Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN), and satellite network.

The mobile application with the features of context-sensitivity and personalisation can support mobile users' work processes and enable them to work together collaboratively and cooperatively in a mobile computing environment with the awareness or use of user location. It can respond to the specific characteristics of mobile computers and wireless networks. The mobile application includes wireless data services and mobile application software. Wireless data services normally provided by Mobile Network Operators (MNO) refer to a wide range of value-added services that could be offered to wireless users. An example of wireless data services contains Personal Information Management (PIM), location-based services, and E-commerce. Mobile application software designed by software programmers are used to support user's specific work processes in various areas. In the construction industry, mobile application software contains the mobile CAD application, data capture application, and project management application.

3.4 MOBILE COMPUTER

Because of the various features and performance capabilities, mobile computers can be grouped into different types, such as smart-phone, pocket PC, pocket PC phone, Tablet PC, and wearable PC. There are also many types of mobile computer accessories, such as portable keyboards, scanners, digital cameras, RFID, and laser distance meters. This section reviews the types of current commercially available mobile computers and accessories. The analysis and summary of mobile computer characteristics in the final framework of mobile computing in construction site information management are discussed in Chapter 6.

3.4.1 SMART-PHONE

The Smart-Phone, as shown in Picture 3.1, has phone capabilities and can run a small set of application software with limited functions. The Smart-Phone can run third-party software and its smaller keypad and screen are designed to give users quick one-handed access to important data. Functions that a smart-phone can perform include email check, calendar tracking and voice notes, but exclude the complex software including Word Mobile, Excel Mobile, and PowerPoint Mobile. Examples of Smart-Phones include the following products, and their pictures and specifications can be found in Appendix 2.

- Cingular 2125 Smart-Phone (Picture A2.1, Table A2.1)
- T-Mobile SDA Smart-Phone (Picture A2.2, Table A2.2)
- Orange SPV C600 Smart-Phone (Picture A2.3, Table A2.3)

Picture 3.1: An example of Smart-Phone

3.4.2 POCKET PC

The Pocket PC including PDAs, Palmtops and Pocket computers, have more powerful data processing capability, slightly bigger screen size, multi-input methods and the ability to connect to Wireless Local Area Network. Picture 3.2 is an example of a rugged Pocket PC. Pocket PCs can run more complex software applications such as Office applications, Microsoft Outlook Mobile, Word Mobile, Excel Mobile and

PowerPoint Mobile. When connecting to a Wireless Local Area Network, users can browse the Internet and send email messages. Examples of pictures and specifications for the following smart-phones can be found in Appendix 2.

- Pharos Traveler GPS 525 Pocket PC (Picture A2.4, Table A2.4)
- CV30 Fixed Mount Computer (Picture A2.5, Table A2.5)
- TDS Ranger Pocket PC (Picture A2.6, Table A2.6)

Picture 3.2: An example of Pocket PC

3.4.3 POCKET PC PHONE

Compared to Pocket PCs, the Pocket PC Phone has all the functions and performance that Pocket PCs contain with the addition of the wireless access to the cellular phone network (Wireless Wide Area Network), see Picture 3.3. However, access to the Internet through a cellular phone network will incur data charges from network providers. Examples of pictures and specifications for the following smart-phones are shown in Appendix 2.

- T-Mobile MDA Pocket PC Phone (Picture A2.7, Table A2.7)
- Palm Treo 750 Pocket PC Phone (Picture A2.8, Table A2.8)
- MC9097-G Pocket PC Phone (Picture A2.9, Table A2.9)

Picture 3.3: An example of Pocket PC Phone

3.4.4 TABLET PC

Computers powered by the Windows XP Tablet PC Edition operating system and equipped with a sensitive screen designed to interact with a complementary pen, are called Tablet PCs; see Picture 3.4. The Tablet PC is a fully-functional laptop PC, but because of its direct interaction with the screen, Tablet PCs are more flexible to use. This means users can use Tablet PCs while standing up or moving around. The following models of Tablet PC, including convertible model, slate model and rugged model are shown in Appendix 2.

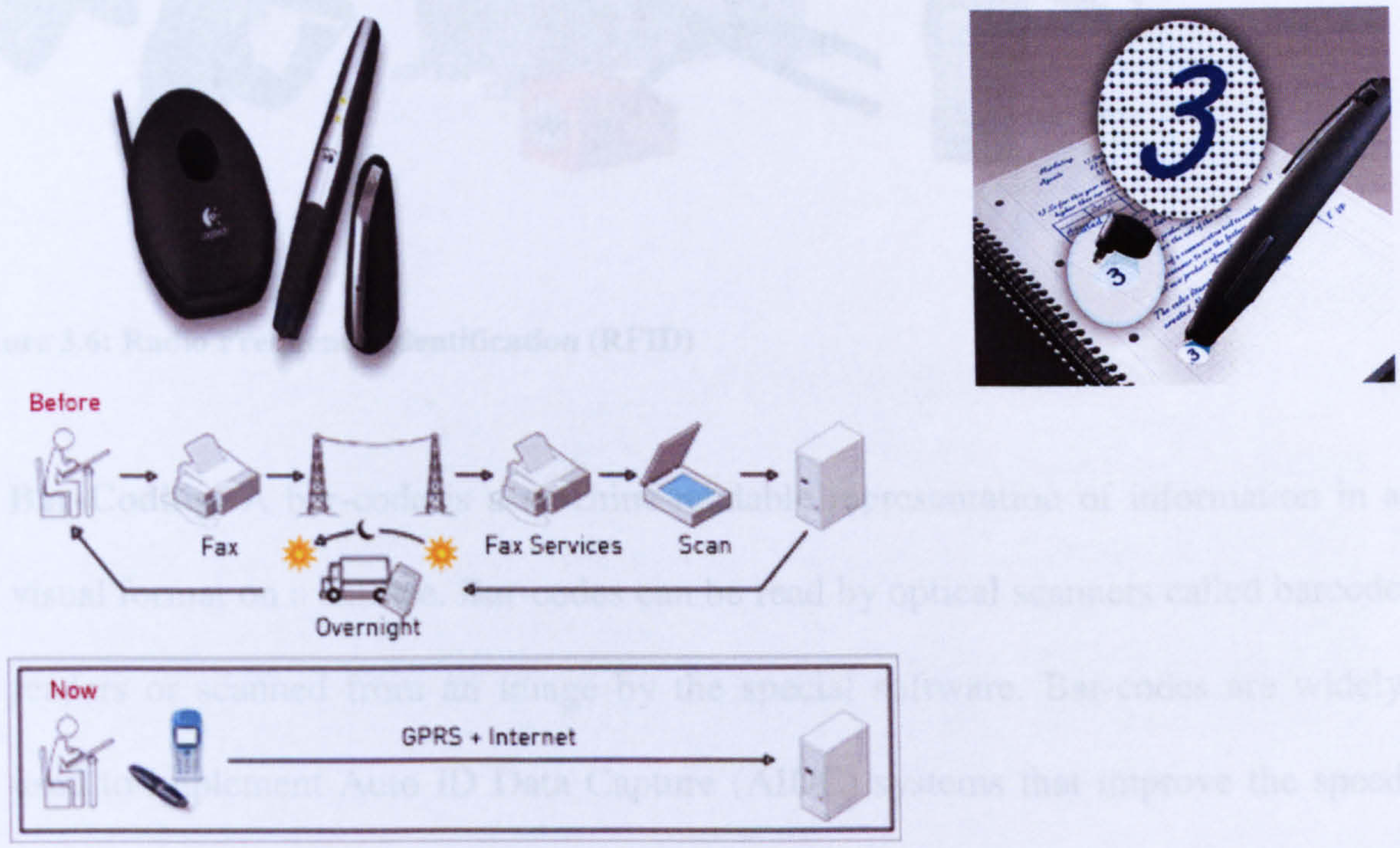
- ThinkPad X60 Tablet PC (Picture A2.10, Table A2.10)
- Stylistic® ST5111/ST5112 Tablet PC (Picture A2.11, Table A2.11)
- Tronix Duo-Touch Tablet PC (Picture A2.12, Table A2.12)

Picture 3.4: An example of Tablet PC

3.4.5 MOBILE COMPUTER ACCESSORIES

There are many accessories for mobile computers in the commercial market. These kinds of accessories are designed to increase the efficiency and effectiveness of data input and output and task performance of mobile computers. Some examples are introduced as follows:

- **Digital Pen**. The digital pen system contains a digital pen, digital papers, and coordinated PC application software, which allows text and images handwritten with the digital pen on digital paper to be transformed into digital data. The digital information can then be transferred to a compatible computer via a mobile phone, Bluetooth, or Internet. Example products, as shown in Picture 3.5, include Nokia Digital Pen SU-27W, Logitech® io™$_2$ Digital Pen, Esselte Anoto, and Easybook M^3.



Picture 3.5: Digital Pen Products

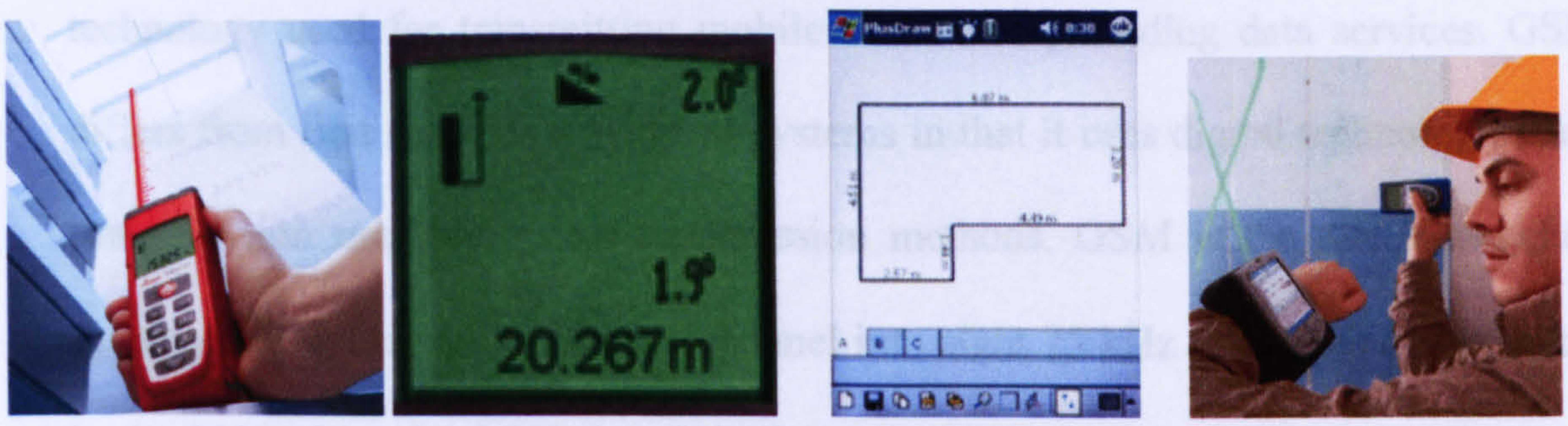
- **Radio Frequency Identification (RFID).** RFID consisting of tags, readers, and antennas, can collect and manage data in a portable and changeable dataset. RFID differs from the bar-coding technology because it uses radio waves instead of light waves to scan a tag. Applications of RFID have two broad categories: infrastructure-based and asset tracking-based environments. The infrastructure-based environment contains automatic vehicle identification (AVI) in road tolling, intelligent transportation systems (ITS), parking, and Homeland Security. The tracking-based environment includes automatic equipment identification (AEI) applications in rail, fleets and container tracking (Picture 3.6).

Picture 3.6: Radio Frequency Identification (RFID)

- **Bar-Coding.** A bar-code is a machine-readable representation of information in a visual format on a surface. Bar-codes can be read by optical scanners called barcode readers or scanned from an image by the special software. Bar-codes are widely used to implement Auto ID Data Capture (AIDC) systems that improve the speed and accuracy of computer data entry. In construction, bar-codes are normally used for the identification and tracking of construction components. Examples of products include PDT 8000 Series, Various systems and Segull Scientific, as shown in Picture 3.7.

Picture 3.7: Bar-Coding Equipment

- **Laser Distance Meter.** The Laser Distance Meter is the hand-held laser equipment for distance measurements of length, squares and volumes. Data recorded by a laser distance meter can be directly transferred to handheld computers via Bluetooth connection. Leica Geosystems is an example of a Laser Distance Meter, see Picture 3.8.



Picture 3.8: Laser Distance Meter Equipment

3.5 WIRELESS NETWORKS

One of the challenges for mobile users in the area of mobile computing is to obtain the support of wireless networks to best meet their data communication requirements. Wireless networks, which have sufficient bandwidth and can be accessed by mobile computers while in motion, can be summarised into the following four general categories: Wireless Wide Area Network (WWAN), Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN) and satellite communication.

3.5.1 WIRELESS WIDE AREA NETWORK

The Wireless Wide Area Network is normally connected with the cellular telephone system that spans over a country or even the world, but only supports low bandwidth (several Kbps) for digital data communication. However, the new emerging Third

Generation (3G) technology can offer theoretical data speeds from 384 Kbps up to 2 Mbps. Previously, services of WWAN have focused primarily on voice communication, but there has been a recent trend of providing mobile data services. Typical WWAN technological standards consist of GSM (Global System for Mobile communications), WAP (Wireless Access Protocol), GPRS (General Packet Radio Service) and 3G.

- The Global System for Mobile communications (GSM) is an open, digital cellular technology used for transmitting mobile voice and providing data services. GSM differs from first generation wireless systems in that it uses digital technologies and time division multiple access transmission methods. GSM is the circuit-switched system that divides each 200 kHz channel into eight 25 kHz time-slots and operates in the 900MHz and 1.8GHz bands in Europe. GSM supports the data transfer speed up to 9.6 Kbs, allowing the transmission of basic data services, such as SMS (Short Message Service). Another major benefit is its international roaming capability that allows users to access same services while travelling abroad. This gives consumers the seamless and same number connectivity in more than 210 countries. GSM satellite roaming has also extended service access to areas where terrestrial coverage is not available.
- The Wireless Access Protocol (WAP) is one of the add-on services for Global System for Mobile communication (GSM). WAP has been designed to work across a whole range of mobile communication systems and was the first attempt to provide mobile Internet services from telecommunication operators. In order to obtain the data communication service, users need to use the WAP enabled mobile phones to access the WAP-gateway that can handle Wireless Mark-up Language (WML) and bridge the telecommunication and data network. The transfer rate of data is from 9.6Kbps to 14.4Kbps.

- The General Packet Radio Service (GPRS) is the standardised packet-switched data service that is the extension of the GSM architecture. GPRS is the connectivity solution based on Internet Protocols (IP) that supports a wide range of enterprises and user applications. With throughput rates of up to 40 Kbps, users have a similar access speed to a dial-up modem, but with the convenience of being able to connect from anywhere. GPRS users can have advanced data services such as colour Internet browsing, e-mail on the move, powerful visual communications such as video streaming and multimedia messages, and location-based services. The GPRS network is only used when data is being transmitted, but users can retain a virtual connection to the chosen wireless network. The use of Internet Protocol (IP) provides the connectivity from GPRS-enabled devices to the Internet and to IP-based company intranets.
- The third generation (3G) of mobile telephony or UMTS (Universal Mobile Telephone Network) has been developed by ETSI (European Telecommunication Standards Institute) and can offer theoretical data speeds from 384 kbps up to 2 Mbps, which are dependent on the software used in the base stations, on the frequencies 1885-2025 and 2110-2200 MHz. The core network is divided in both circuit switched and packet switched domains. Circuit switched connections that handle the voice and packet connection protocol is designed for data delivery. The ATM (Asynchronous Transfer Mode) is defined for UMTS core transmission.

3.5.2 WIRELESS LOCAL AREA NETWORK

Compared with WWAN, Wireless Local Area Network (WLAN) can provide high data rate access but the geographic coverage is limited. The most common way to access a wireless local area network is through the network interface card (NIC) that then communicates with a base station (Access Point) located in the vicinity. The most common protocols used for WLAN are IEEE802.11 and HomeRF.

- Wireless LANs were first introduced in 1997 with two different technologies: one for corporate environments (IEEE 802.11) and one for home networks (HomeRF). IEEE 802.11a is designed to achieve a transmission range of 30 up to 100 metres and supports a data rate of 54Mbps while operating in the 5GHz UNII (Unlicensed National Information Infrastructure) band. IEEE 802.11a is approved in the US and the Far East, but not in Europe or Japan. In 1999, IEEE approved a revision of the IEEE 802.11a standard, which is called 802.11b, with the provision of much higher data rates (5.5 and 11Mbps) while maintaining the 802.11 protocol. The 802.11b standard is designed to achieve a transmission range of about 30 to 100 metres and operate in the 2.4GHz ISM band using the DSSS (Direct Sequence Spread Spectrum) technology. The IEEE 802.11b standard uses a CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and an identical MAC (Media Access Control) as Ethernet. The shared-key encryption mechanism called WEP (Wired Equivalent Privacy) is included in the specification of IEEE 802.11b. Efforts are underway to increase the performance of 802.11b standard to the speed of 22Mbps or even up to 54Mbps, which will be the new protocol called 802.11g.
- The HomeRF was developed from the beginning to bring wireless networking to users in their home using RF (Radio Frequency). The HomeRF protocol operates in the globally available 2.4GHz ISM (Industrial, Scientific and Medical) band using FHSS (Frequency Hopping spread Spectrum). First generation HomeRF products have peak data rates of 1.6Mbps and cover virtually all homes and small offices with a 50-metre typical indoors range. Second generation HomeRF products (HomeRF 2.0) were shipped in October 2001. This new version uses 10Mbps peak

data rates while still providing entire home coverage. HomeRF is fully backward compatible.

3.5.3 WIRELESS PERSONAL AREA NETWORK

Compared with long-range wireless networks, the technologies that solve the problems of communication in small places have been created to provide the means of short-range radio connections via embedded wireless devices. The Wireless Personal Area Network typically covers a few metres surrounding a user's workspace and provides the ability to synchronise mobile devices, transfer files, and gain access to local peripherals like printers and a range of pocket hardware. The typical technological standards include Bluetooth and IrDa.

- Bluetooth is the low cost and low power wireless connection method that supports a transmission range up to 10 metres with a small footprint, which makes it suitable for cable replacements. Bluetooth emerged in 1994 at Ericsson Mobile Communication. In February 1998, five companies including Nokia, IBM; Toshiba and Intel, formed the Bluetooth SIG (Special Interest Group). Bluetooth communication occurs in the same unlicensed band as 902.11 and HomeRF, the ISM band at 2.4GHz. Bluetooth uses a spread-spectrum frequency-hopping technique to protect against interference and each network may control up to eight devices. The communication channel can support both data (asynchronous) and voice (synchronous) communications with a total bandwidth of 1Mbps. The key benefits of Bluetooth are the minimal hardware dimensions, low price of components, and low power consumption.
- The most established technology in the cable replacement market is the IrDA (Infrared Data Association) that can provide wireless solutions for serial data

connections between notebook PCs and controlling devices. The technique is well known in the market and around 100 million ports have been installed. IrDA is relatively simple to configure and use with suitable software support. IrDA for data transfer has the advantage of a high throughput (payload) compared with other standards such as Bluetooth, but IrDA is limited by two aspects: the point-to-point connection and the need for line-of-sight for its infrared beam.

3.5.4 SATELLITE COMMUNICATION

Satellite-based data communication can be viewed as expensive base stations providing the wide-area coverage. It can provide services similar to those provided by cellular phone networks. These services typically include the limited quality two-way voice, circuit-switched or packet-switched data, and paging. The advantage of satellite communication is its capability to cover a widespread area, but the cost is much more expensive than other wireless networks.

Satellite systems range from low earth orbit satellites (LEOS), through medium earth orbit satellites (MEOS), to geostationary earth orbit satellites (GEOS). In general, the further the satellite is from the earth, the larger the coverage region. This decreases the user capacity within a given spectrum allocation and also decreases the number of satellites required to cover a given geographical location. The difference in transmission delay between the locations of the satellite can be upwards of two orders of magnitude, large transmission delays impact the quality of two-way voice communications.

American Mobile Satellite Corporation (AMSC) was the first commercial service provider for terrestrial mobile radio services, which provides the user with both cellular and satellite-based services. The service provides both satellite-based voice telephony and circuit-switched asynchronous data using a built-in modem. The circuit-switched modem provides transmission rates of between 1200-4800bps for data.

3.6 MOBILE APPLICATION

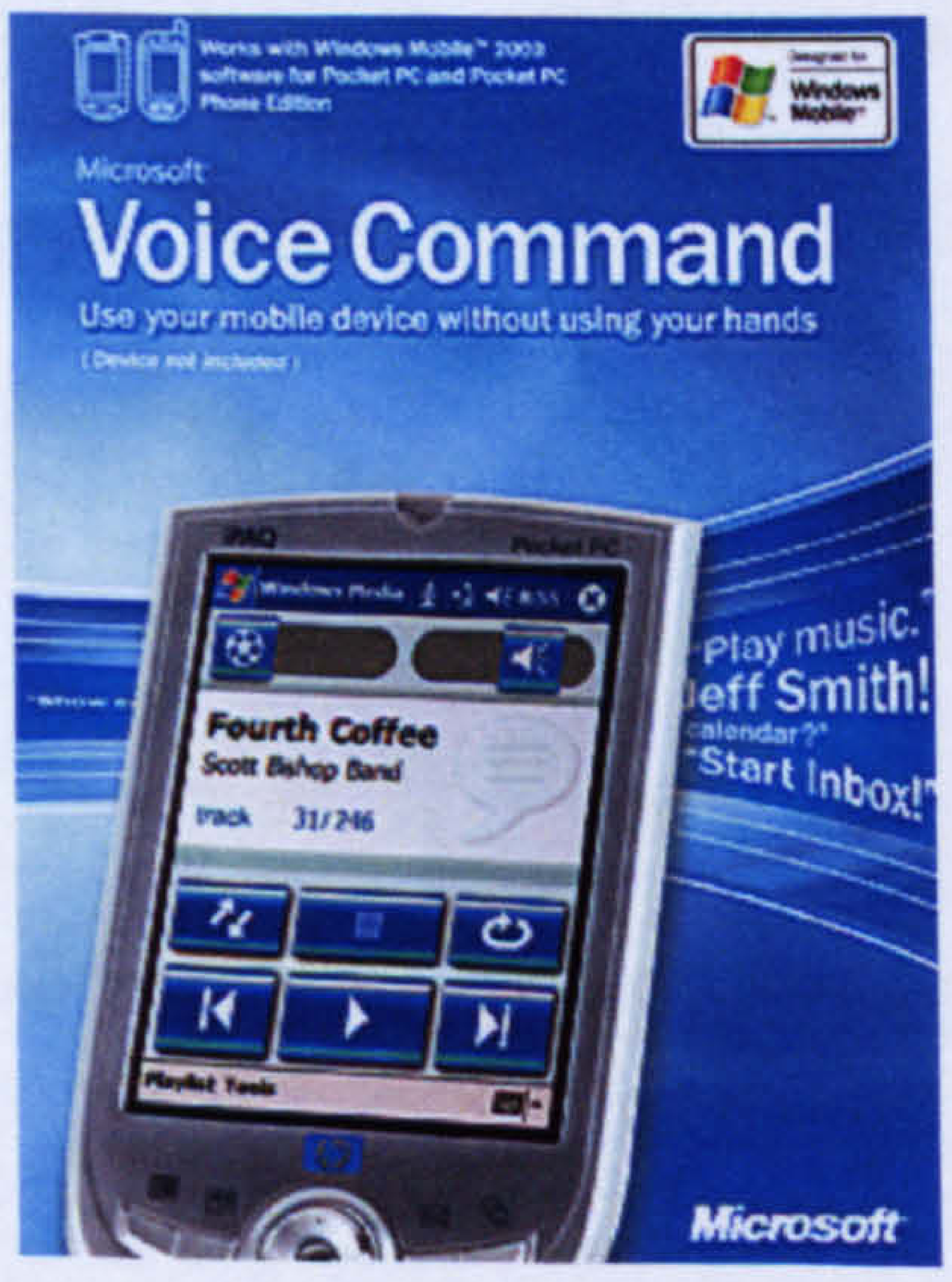
Mobile application has the attributes of context-sensitivity and personalisation to support users' work processes in a mobile computing environment. It enables users to work together collaboratively and cooperatively with the awareness of user's location, and can respond to the specific characteristics of mobile computers and wireless networks. Mobile application includes wireless data services and mobile application software. Wireless data services normally provided by Mobile Network Operators (MNO) refer to a wide range of value-added services that could be offered to wireless users. Mobile application software is the software designed by software companies to support user's specific work processes in a particular area.

According to its features and utilisations, mobile application software can be classified into different categories, such as business application software, utility software, entertainment software, and mobile professional applications.

- Business application software can help users to manage personal information, send emails, view and edit Word documents, explore the Internet, manage business files, organise personal calendar, and update to-do lists. Examples include Microsoft Office Mobile, Outlook Mobile, Internet Explorer Mobile, Pocket Informant, and SPB Pocket Plus (Picture 3.9).

Picture 3.9: The snapshot of SPB Pocket Plus

- Utility software can perform specific mobile computer tasks in order to increase the performance of the mobile computer, add more computing functions, run maintenance tasks, manage computer hardware, backup mobile computer files, and protect mobile computers from computer viruses. These kinds of mobile software include Microsoft Voice Command, Pocket Mechanic Professional, PDAnet for PDA Mobile, and Pocket Hack Master. Picture 3.10 is the snapshot of Microsoft Voice Command.



Picture 3.10: The snapshot of Microsoft Voice Command

- Users using mobile entertainment software can play games, watch video streams, listen to music, and chat with other people through instant communication software such as Pocket MSN. Examples of mobile entertainment software include Pocket DVD Studio, HandiTV, PocketStreamer Pro, and a great number of games. Picture 3.11 is the snapshot of the game 'Age of Empires'.

Picture 3.11: The snapshot of Age of Empire

- Mobile professional applications refer to the software that assists users to perform their professional works in specific areas. For example, physicians and nurses can use mobile healthcare software in their symptoms assessment, diagnoses, and treatments while they are inspecting patients around different medical wards. In the construction industry, mobile application software is generally divided into three groups: mobile CAD application, data capture application, and project management application, which are discussed in great depth in Section 3.9.1. Picture 3.12 is the snapshot of the Pocket CAD Viewer.

Picture 3.12: The snapshot of Pocket CAD Viewer

3.7 WIRELESS DATA SERVICES

Wireless data services refer to the wide range of value-added services that could be offered to mobile users. Typical examples of wireless services provided by Mobile Network Operators (MNO) are shown in Table 3.1 (Preez and Pistorius, 2001). These services can be accessed not only via smart-phone but also other devices such as pocket PC phones. All of these mobile computing devices are commonly used for access to electronic mail, sending faxes, accessing the Web or remote databases. Pocket PC phones that integrate pocket PC with a cellular phone could be used as an electronic "newspaper" capable of delivering selective news that are personalised according to individual user preferences and is more up-to-data than a paper-based newspaper. Web-based news is already available, and access to multimedia entertainment, videos, music, and games is likely to increase in the future.

Market segment	Service categories	Specific services
Consumer	Information services	News headlines; market and financial information; new mobile releases; "what's on"
	Personal information management (PIM)	e-mail; contact lists; shared scheduling; customised alerts for stock market prices or auction bids
	Location-based services	Directions from current position to a specified location; queries for various facilities (e.g., hospital and restaurant) in the user's vicinity
	Entertainment	Video and audio on demand; mobile betting and gaming
	M-commerce	Mobile banking, shopping and stock trading; mobile auctions; e-booking and ticketing
	Interactive communication	One-to-one or multiple participant text-based chat; video telephony and conferencing; interactive games. Remote control of appliances (e.g., alarm/VCR setting)
Business	Job and information dispatches	Informing field staff of their next assignment (e.g., plumbers, electricians and technical support staff). Sending of information to multiple recipients (e.g., notifications of meetings). Focused/personalised advertising
	Remote transactions	Remote control of processes and devices; placing and processing customer orders
	Remote access to information	Sales force automation through access to stock, product and customer information; remote access to intranet or other corporate repositories; e-mail; online telephone directories
	Telemetry/device-to-device	Price changes being sent from a central controller to all vending machines; meter readings; remote vehicle diagnostics

Table 3. 1 Examples of wireless data services and applications that could be offered (Preez and Pistorius, 2001)

Other wireless data services include a range of location-aware applications in which mobile computers can determine users' physical location (Chalmers and Sloman, 1999). For example, Global Positioning Systems (GPS) can be used to display current positions on maps, receive traffic and weather information, and act as a car navigation aid system. This could be enhanced to provide local information such as the nearest hospitals, hotels or restaurants for travellers and determine the current position of the user with the information on buildings near the user. A good example is the TomTom GPS Navigator.

However, the adoption of wireless services offered by Mobile Network Operators (MNO) has not been very high due to three main factors (Preez and Pistorius, 2001).

- The typical data transfer rate achievable on GSM (Global system for Mobile Communications) network is 9.6 kbps, which leads to user frustration with long download times. The low transfer rate also severely limits the richness of information and complexity of the wireless data services and applications that can be offered. As an example, the data transfer rate required for streaming audio to a mobile device is around 32 kbps and for video services around 128 kbps.

- Data transmission on GSM is circuit-switched, meaning that a circuit connection is dedicated to a specific user for the entire length of the call, even when no information is being transmitted (and hence the user pays for the entire connection time instead of for the amount of data accessed or transferred during that time). A user also needs to dial up the service centre every time a service or application is accessed; with call and connection set-up times in the region of 50 seconds; this contributes to a frustrating user experience.
- Most operators offering data services on a GSM network have billed for these services in the same way as for voice services, i.e., duration-based billing (per minute or in more advanced cases per second). There are several more appropriate billing mechanisms for data services, such as volume-based billing (per packet or bit of information downloaded or accessed).

3.8 RESEARCH IN MOBILE COMPUTING APPLICATION

There are many research papers which address the issue of the mobile computing application with focus on increasing the efficiency of wireless data communication and information exchange. Some early papers tried to give a general view of building a technology framework for information access in a mobile computing environment. For example, the paper on designing mobile computing systems using distributed objects

(Chen and Suda, 1997) discussed issues and problems in constructing a dynamic distributed object-oriented architecture capable of supporting mobile computing. The paper on client-server computing in a mobile environment (Jing et al., 1999) introduced the mobile-aware adaptation, extended client-server model and mobile data access.

Topics on mobile computing database access (Barbara, 1999; Papastavrou et al., 2000) concern the issues of data dissemination over limited bandwidth channels, location-dependent querying, advanced interfaces for mobile computer, and Java-based mobile agents for Web-based database access. Web searching with PDAs (Buyukkokten et al., 2000a; Buyukkokten et al., 2000b) examines the issues of interaction with the World Wide Web via wireless-connected PDAs within some limitations in terms of bandwidth, screen size, battery capacity, and time costs of a pen-based search key word.

The restriction of input and output interface is one of the major challenges in accessing, synthesizing and modifying the large amounts of data on mobile computers, These restrictions were attempted to be addressed from the perspective of Human Computer Interaction (HCI) by many researchers (Buchanan et al., 2001; Buyukkokten et al., 2000b; Mohd-Nasir, 1999; Pilgrim et al., 2002b; Reinhardt and Scherer, 2000). Another approach used in overcoming the limitations of mobile computers is to provide users with context-relevant information and services based on the information of their context; such as the identity of the user, temporal information, location, time and proximity-based context sensing (Aziz et al., 2004; Dahlem et al., 2003; Singhvi and Terk, 2003; Toivonen et al., 2003).

Some research projects have been conducted to address the problems of what types of tasks are suited for mobile computers and how mobile computers can operate specific tasks. In order to evaluate the extent to which mobile computers can be used by users to meet their specific requirements, an example of usability testing was carried out by Bowden et al. (Bowden et al., 2003) who assessed the use of commercially available mobile devices to do different types of construction tasks on a construction site. The possibility of using Pocket PC coupled with multiple VR applications as a 3D visualisation device was discussed by Frairuz Shiratudin et al. (2002). They found that its current status is limited by very few 3D application and limited 3D graphics, but they anticipated that more applications related to both 2D and 3D visualisation could be ported to the Pocket PC in the future. In Pilgrim's research (Pilgrim et al., 2002a) they examined the application of using mobile devices to perform engineering calculations with the aim of designing human computer interface and data representation.

3.9 MOBILE COMPUTING IN CONSTRUCTION

The development of Information Technology (IT) gives the construction industry a powerful potential to increase the efficiency and effectiveness of information exchange, but current IT support has only extended to construction site offices resulting in gaps between design and construction. Mobile Computing (MC) has the potential to enlarge the boundary of information systems from site offices to actual work sites and therefore to integrate design and construction. This section focuses on the mobile application software in construction, a review of mobile computing technologies used in the industry, the evaluation and practice of mobile computing in a real construction environment, and the benefits and potential for applying mobile computing in the construction industry.

3.9.1 MOBILE APPLICATION SOFTWARE IN CONSTRUCTION

Mobile application software running on mobile computers with the connection to wireless networks can support user's specific work in various areas. In the construction industry there are three main types of mobile application software, including the mobile CAD application, data capture application, and project management application.

3.9.1.1 Mobile CAD Applications

CAD is the software used in nearly all construction projects to produce construction drawings for users who conduct construction activities on construction sites. However, although construction drawings are created electronically, construction personnel always print out them and take paper-based drawings to construction work sites for their needs. Mobile CAD applications running on mobile computers can support construction personnel to view, mark-up, create, edit and collaborate on 2D/3D CAD compatible designs and digital blueprints anywhere and at anytime when they walk around on construction work sites. Examples of mobile CAD applications include:

- **PocketCAD.** PocketCAD (in Appendix 2, Picture A2.13) is the mobile application software that runs on Pocket PCs and supports the migration of construction drawings from desktops to Pocket PCs and back again via CadExchange in conjunction with Microsoft ActiveSync. Because it supports both Autodesk and MircroStation, this application is compatible with Autodesk DWG, DWF, and DXF files as well as MicroStation DGN files. PocketCAD has comprehensive features including data creation, collection, viewing, drawing, and modification, shown in Appendix 2, Table A2.13.

- **PowerCAD CE.** PowerCAD CE (in Appendix 2, Picture A2.14) is the full-featured CAD and CAD development system optimised for portable/wireless computing devices running Windows CE (the latest 5.6 version can run on Windows Mobile 5). PowerCAD CE allows users to create designs from scratch or modify existing DWG, DXF, or FLX designs while they are in motion. It also supports complete Lisp or C/C++ customisation and programming. Features of PowerCAD are shown in Appendix 2, Table A2.14.
- **ZipCAD.** ZipCAD (in Appendix 2, Picture A2.15) is the full-featured 2D CAD program that runs on Palm OS PDAs and Treos. By using ZipCAD construction drawings can be marked up and annotated on construction work sites and exported back to desktop computers at the site office. DXF files can be exported directly to the PDA's SD card and emailed remotely. ZipCAD has large number of tools and settings such as draw tools, build tools, select tools, view tools, snap preferences, and user preferences.

3.9.1.2 Data Capture Applications

Mobile data capture applications (in Appendix 2, Picture A2.16) are designed to assist users to capture, collect, store and transfer information on construction work sites. There are three types of data capture applications used in the field: traditional data capture applications, bar code scanning applications and wireless sensor networks. Examples of application software include the following:

- **Traditional data capture applications.** Stent Handheld ElectRonic Piling Assistant (SHERPA) (Ward et al., 2003; Ward et al., 2004) is one of the mobile data capture systems, which enables users to utilise workforce driven mobile computers to collect real time piling work data on construction work sites via a Wireless Local Area Network (WLAN). The SHERPA system consists of three main components: a site based server-side database, an IEEE802.11b wireless local area network, and thin-client mobile computers. The server-side database can store and manage a centrally located work schedule and provide access to incoming data for analysis and re-use. The WLAN can provide the mobility for data capture and access to shared data source, and the client-side mobile computer can be used by construction personnel to collect data and provide user access to the remote information resources.

- **Bar code scanning applications.** A bar-code-enabled PDA application, named the Mobile Construction Supply Chain Management system (M-ConSCM), has been developed to improve the effectiveness and convenience of information flow in a construction supply chain environment through integrating a bar code scanner with a PDA together (Tserng and Dzeng, 2005). The M-ConSCM is a web-based system utilised to effectively integrate general contractors, subcontractors, and suppliers, such that construction merchandise is made and distributed in the right quantities, to the right locations, at the right times.
- **Wireless sensor network.** The wireless sensor network that consists of various devices capable of a cooperative sensing task is a new innovative technology similar to the concept of Ubiquitous Computing. A mass concrete curing management system (CMS) has been developed to investigate the possibility of applying the wireless sensor network to on-site data collection processes (Lee and Kang, 2006). This system can allow the collection, transfer, and delivery of the data of recorded

curing temperature automatically in real time in a wireless sensor network environment.

3.9.1.3 Project Management Applications

Mobile applications in the project administration area provide users with the capabilities of project and programme management via users' on-hand mobile computers. These project management tasks include construction activity review, activity monitoring and updating, progress management, risk management, Microsoft Project file view and update, and material and equipment management. Examples (Appendix 2, Picture A2.17) include the following:

- **Primavera Mobile Management.** Primavera Mobile Management running on the Palm OS and Microsoft Pocket PC computers enables field managers to quickly review and update their activities and share these changes with the overall project schedule including the entire project team in the project process. Features of Primavera Mobile Management include the review and status of activities, simple interface, update anywhere, support for both Palm and Pocket PC devices, and activity updating system.
- **cyTools – Project Management Tools.** cyTools allows users to view and update Microsoft Project files on mobile computers. It can analyse, extract and synchronise Microsoft Project files to mobile computer systems. This application also supports many business graphic views including the GANTT charts, resources, earned value and work breakdown structure.
- **OnSite Field Data Management.** OnSite Field Data Management is Desktop/Handheld application software designed for collecting, storing and distributing project management information on work sites. By using OnSite

coupled with Palm Handheld devices, users can easily track punch-list items and daily reports and then upload this information to a central desktop database. From this database, the information can be sorted by item, location, subcontractor, trade, and date to ensure the work gets done correctly and on time.

3.9.2 THE IMPLEMENTATION OF MOBILE COMPUTING IN CONSTRUCTION

Research on mobile computing applications in construction began in earnest in the mid-nineties. Much research focuses on detailed aspects of mobile computing technologies, or developing mobile computing solutions for single or several construction processes. This research can be viewed from two viewpoints: the technology-push viewpoint and the problem-driven viewpoint. Research from the technology-push viewpoint is centred on the implementation of technologies that the general developments in mobile computing research can offer. In contrast, research from the problem-driven viewpoint would be to study the current information management in the construction industry and to identify potential areas where mobile computing technologies can be implemented.

Research that mainly focuses on mobile computing technologies and how to apply these technologies is summarised and reviewed as follows:

- **Context Sensitive.** One of the major potential of applying mobile computing is that additional information, including users' positions, user ID, device ID, surrounding information of users, user activities, time factors, project status and environmental elements, are available from terminal points, which refers to the context sensitive technology. Singhvi and Terk (2003) described the software architecture of a context-awareness system – Prophet that enables construction personnel to maintain continuous access to data and services while they move around the construction site by utilising the knowledge of a user's context. The primary element in this system is the user's position which is handled by using a GPS service when outdoors and by a modified RADAR system when inside a building. Oloufa et al. (2003) focused on equipment tracking that concerns the position of construction equipment and aims to integrate a Differential Global Positioning System (DGPS) with wireless networks and web-based technologies for equipment collision detection. Menzel et al. (2002) discussed the usage of multidimensional data management and the agent technology to achieve a context-sensitive process and data representation. In their later research (Menzel et al., 2004) they classified the context-sensitivity parameters, defined the concepts of multi-dimensional data management by using the metaphor of a data, and finally proposed a system architecture for context-sensitive presentation of process and data management.

- **Speech Recognition.** Because of the limitation of Human Computer Interaction (HCI), speech recognition technology for mobile computers has been introduced into the domain of the construction industry. Research in this area include the use of speech recognition in bridge inspection (Sunkpho and Garrett, 2000), the support of navigation through drawings by using speech commands (Reinhardt and Scherer, 2000), and the advantages of using speech recognition along with VoiceXML technology for voice-enabled construction field applications (Kondratova, 2004).
- **IP Telephony.** Construction companies traditionally use several off-the-shelf telecommunication tools and techniques such as two-way radio transceivers and walkie-talkie, to provide communication to mobile personnel on construction work sites. The emergence of Internet Protocol (IP) Telephony communication systems

has the potential to alternate such traditional telecommunication systems. Beyh and Kagioglou (2002) proposed a theoretical framework to integrate Internet Protocol (IP) Telephony onto construction sites communication infrastructures and to overcome the implementation barriers. In their later research (Beyh and Kagioglou, 2004) they further explored various models of communication under this common framework and outlined some of the implementation issues including the business case for an improved way of working.

- **Wearable Computer.** A wearable computer is a small portable computer that is designed to be integrated into the user's clothing or attached to the body through other means such as a wristband. Wearable computers differ from PDAs that are designed for hand-held use. Wearable computers normally integrate other technologies including wireless networks, speech recognition, touch screens, eye-tracking or lip-reading interface, head-worn display, and chest-worn display. Research that aims to introduce wearable computers into the construction industry include the design of wearable computers for supporting construction progress monitoring (Reinhardt et al., 2000), the interaction between users and wearable computer systems (Burgy and Garrett, 2002), wearable computers for field users (Garrett and Sunkpho, 2000), the model for site visits using wearable computers (Mills and Beliveau, 1998), the test of wearable computers in a real-life construction situation (Fuller et al., 2000), and the mobile video system (Miah et al., 1998).
- **Bar-coding Technology.** The bar-code system is the automatic identification solution that streamlines identification and data acquisition. The bar-code-enabled mobile computer that integrates a bar code scanner can be a powerful portable data collection tool that enables on-site construction personnel to seamlessly integrate work processes. Applications of bar-coding technology in the construction industry

include material and build components management on construction work sites (McCulloch and Luepraser, 1994; Skibniewski and Wooldridge, 1992), equipment tracking and management on construction sites (Wirt et al., 1999), the identification of documentation and drawings (Finch et al., 1996b; Stukhart and Cook, 1990), and construction supply chain management using PDA and bar codes (Tserng and Dzeng, 2005). According to the findings from their survey, Marsh and Finch (1998) identified the barriers which have prevented construction organisations from using auto-ID technologies, and then suggested future developments which are perceived as important in encouraging more widespread adoption of the technology.

- **Wireless Sensor.** Wireless sensors are small devices which are capable of performing a sensing task. A Wireless Sensor Network consisting of a central station and one or more remote stations is a network of such devices capable of a cooperative sensing task. Through a number of possible implementation scenarios, including health and safety applications, asset tracking, logistics, building monitoring and provision of equipment maintenance information, Domdouzis et al. (2005) illustrated the potential benefits of Wireless Sensor Networking technology in the construction industry. Delsing et al. (2004) described the proposed architecture based on heterogeneous sensor and actuator devices accessible over the Internet, and Lee and Kang (2006) applied the wireless sensor technology into a mass concrete curing management system that consists of three components – wireless data acquisition, strength estimation and an alarm.
- **Mobile Ad-hoc Network.** There are many wireless networks that can be used on construction sites, such as GPRS, UMTS, and WLAN. Kuladinithi et al. (2004) discussed a new wireless network protocol called Ad-hoc network and provided a detailed scenario to explain how mobile ad-hoc networking can be used in the

construction industry. The fundamental nature of these networks is that mobile devices can communicate between each other without relying on external networking infrastructure.

- **Ubiquitous Computing.** Ubiquitous Computing has two important characteristics: the universal accessibility of devices to information services and the collaboration among the parties accessing the information services. In order to address these two fundamental issues, Liu et al. (2003) developed a software framework for the development of a ubiquitous computing environment for distributed engineering information services. They indicated that a ubiquitous computing environment will help on-site construction personnel to more effectively communicate with each other.

In addition to the focus on detailed mobile computing technologies, the concentration on the development of mobile computing systems for specific construction processes and the integration of them into existing IT-infrastructure include the following developed systems:

- **Data Collection System.** Ward et al. (2003) developed a mobile site level data collection system called the Stent Handheld ElectRonic Piling Assistant (SHERPA) for on-site piling works. This system enables on-site construction personnel to share real-time piling information via mobile computers accessing a centrally site-located database through a mobile Wireless Local Area Network (WLAN). Ward et al. (2004) further implemented this system on two construction sites to evaluate the difficulties, barriers, benefits, and user's experiences, and provided recommendations for further work. The potential of using mobile computers in keeping site records has been discussed by Scott (Scott, 1990; Scott and Assadi, 1997).

- **Mobile Construction Management System.** In order to assist construction managers to manage different types of information, Kimoto et al. (2005) developed a mobile computing system for the management of information on construction sites. The structure of this system contains the data input program installed in the mobile computer and the output and analysis program installed in the desktop computer. The data transfer is through the memory card that records data in the mobile computer and transfers data back to the desktop. This mobile computing system contains four sub-systems including the inspection system, checklist and reference system, position check system, and progress monitoring system. These sub-systems can assist construction managers to manage their required information on construction sites.
- **On-site Problem Solving System.** Unanticipated events on construction sites are inevitable and immediate on-site problem solving has a major impact on subsequent project characteristics. The on-site problem solving system (Magdic et al., 2004) implemented mobile computing technologies with a concentration on interactive personal communication as a basis for immediate on-site problem solving.
- **Construction Site Inspection System.** Construction site inspection has been seen as a potential area for applying mobile computing technologies. Developed systems in this area contain the field inspection support system for civil system inspection (Sunkpho et al., 2003), the mobile manipulator imaging system for bridge crack inspection (Tung and Hwang, 2002), and the field supervision and bridge structure inspection system (Mills and Wakefield, 2003).
- **Mobile Operations Support System.** The COSMOS (Construction Sites Mobile Operations Support) system (Meissner et al., 2002; Meissner et al., 2003) integrates wireless networks and the business applications designed for supporting on-site

construction operations. Network coverage on the construction site is provided by Wireless Local Area Network (WLAN) and the link between the construction site and the company headquarters is established via a satellite communication link. This system can allow construction engineers and managers to access business and technical information stored at the remote headquarters.

- **Mobile Construction Collaboration System.** The aim of construction collaboration systems is to solve the fragmentation problems in the industry, but traditional web-based collaboration systems are not in common use in the field by foremen and site engineers. The flow of construction information is disconnected before reaching construction work sites. The mobile construction collaboration system aims to address this issue by extending key collaboration features to on-site users through the implementation of mobile computers, wireless networks and mobile applications. Research in this area includes the semantic web based services for mobile construction collaboration (Zeeshan et al., 2004) and mobility support for distributed collaborative teamwork (Johanson and Törlind, 2004).

3.9.3 EVALUATIONS AND PRACTICES OF MOBILE COMPUTING IN CONSTRUCTION

When new information technology overtakes older technical solutions, the new technology should become more consistent and reliable. Because of the specific characteristics of the construction industry, such as the fragmentation, field works, the integration of various project partners and less formalised construction processes, and the complexity of mobile computing technologies in terms of the diversity of mobile computers, the huge distinction in features between wireless networks, and the difficulty of designing human computer interaction, there are important questions that should be addressed before applying mobile computing in the industry. These questions include: can mobile computers be used on construction sites; how do users use mobile computers on construction work sites; do wireless networks have sufficient capability to transfer construction information; how can mobile networks be established at construction sites; how can mobile computing systems be embedded in construction processes and integrated into the existing IT infrastructure; and what are the significant differences between the traditional construction process and the re-engineered process using mobile computing, which is called the "mobilised" process?

Research that targets the above questions includes the evaluation of mobile computers on construction work sites, examination of on-site wireless networks, estimation of the whole mobile computing system, construction process comparison, and the practice of mobile computing in a real construction situation. Some relevant research is introduced as follows:

- **Mobile Computer Evaluation.** The use of mobile computers in construction should consider the following issues: the specific construction site environment, the limitation of Human Computer Interaction (HCI), the limited computing capability, and the user's perception of using new technologies. Research evaluating mobile computers in the construction industry contains the usability testing of hand held computers on real construction sites (Bowden et al., 2003), the assessment of mobile devices for engineering analysis (Pilgrim et al., 2002a), the test of 3D visualisation applications using the pocket PC (Shiratuddin et al., 2002), and the comparison of applying different types of mobile computers on construction sites (Elvin, 2003; Fuller et al., 2000).

- **Wireless Network Examination.** Construction sites are information intensive environments and the places where actual construction activities are carried out. In order to investigate the capability of wireless networks for transferring construction information, de la Garza and Howitt (1998) assessed the extent to which wireless networks can fulfil the user's information needs on construction work sites. They firstly identified the construction information that users need on work sites with the information attributes of formats, timing, size, type, importance and data rate. Wireless communication technologies were then reviewed and classified into five classes. Finally researchers examined the trade-off to determine if a given wireless technology could be considered as a viable way to meet user's information needs on construction sites. Another research project is the MICC project (Mobile Integrated Communications in Construction) (Deguine et al., 1999) that test different wireless communication technologies for voice services and data services with headquarters.
- **Mobile Computing System Evaluation.** Instead of the evaluation of a single aspect of mobile computing, Magdic et al. (2002) conducted an experiment concentrating on the whole mobile computing system at a road construction site. This test examined the characteristics and potential of commercially available PDAs, the possibilities for using cell phone networks for data communication, and the integration of CAD and GIS application software into a mobile document management system.
- **Construction Process Comparison.** In order to introduce mobile computing technologies into the construction industry, the comparison between traditional construction processes and the re-engineered processes with using mobile computing, which is called the "mobilised" process, will investigate the potential of mobile computing to add value to a construction project through impacts on time,

money, safety, rework and productivity. Saidi et al. (2002) compared six construction processes with the estimation of total activity time both with and without the use of mobile computing, and provided an indication for construction tasks that were suited to the use of mobile computing and those that were not. As part of the COMIT project (Construction Opportunities for Mobile IT), Bowden et al. (2004) identified ten construction processes with the graphical representation for both "As Is" processes that are traditional processes and "To Be" processes that use mobile computing. All of the "As Is" and "To Be" processes were presented to construction professionals who selected four processes that can mostly illustrate process changes with the use of mobile computing.

- **Practices in a Real Construction Environment.** The practice of implementing mobile computing in a real construction environment and integrating it into real construction processes can expose problems hid in the system design stage and provide experience for future research. Ward et al. (2004) implemented a mobile site level data collection system for the information management of piling works in two real construction projects and discussed some issues including the application problems encountered, benefits, user perspectives, cost benefit analysis, and recommendations for further work.

3.9.4 POTENTIAL, CHALLENGES AND BENEFITS

Mobile computing technologies have been recognised as having potential in the construction industry and have already been rapidly applied in various types of construction fieldworks. Saidi et al. (2002) recommended the potential construction tasks that are suited for mobile computers and others that are not suited, see Table 3.2.

Tasks that are Suited	**Example**
Tasks that require access to large amounts of text information	Reading MSDS (Material Safety Data System) 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, etc.
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 3D construction drawings
Tasks that require a "big-picture" view of a document	Viewing a drawing or a network schedule
Tasks that require a constant 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, and etc

Table 3. 2 Tasks for which mobile computers are and are not suited (Saidi et al., 2002)

Through a review of the current state of mobile computing and an investigation of several case studies, the research project Construction Opportunities for Mobile IT (COMIT) (ARUP, 2003) identified potential construction processes that could benefit from the use of mobile computing and provided an indication of which technology would be appropriate for each process (Table 3.3).

Technology/Process Matrix			Applicable Technology											
			PDAs	Combined phone/PDAs	Mobile Phone / Video Phone	Hand-Held Computers	Pen Tablet / Touch Computer	Anoto Functionality	RFID	Bar-coding	Digital Hard hat	Wearable Computer	Radio Comms.	GPS/GPRS
Process	Communications	Site worker to site worker						Y					Y	
		Office to foreman & vice versa	Y	Y										
		Design prof. to site manager & vice versa	Y	Y				Y						
		Service record of plant equipment						Y	Y					
		Condition record of fixed assets						Y	Y					
		Warning systems to workers (underground services / overhead power lines)												Y
		Rail warning systems												Y
	Data Capture	Goods received						Y		Y				
		Document transmission / capture	Y	Y		Y	Y	Y						
		Site diaries	Y				Y	Y						
		Task allocation & progress	Y				Y	Y						
		Location of plant and equipment												Y
		Performance / condition of plant and equipment						Y	Y					
		Operative ID						Y	Y	Y				
		Piling Operations					Y	Y						Y

Technology/Process Matrix			Applicable Technology											
			PDAs	Combined phone/PDAs	Mobile Phone / Video Phone	Hand-Held Computers	Pen Tablet / Touch Computer	Anoto Functionality	RFID	Bar-coding	Digital Hard hat	Wearable Computer	Radio Comms.	GPS/GPRS
Process	Data Capture	Monitoring Concrete pours						Y	Y		Y			
		Comparison of planned to actual ops.				Y	Y		Y		Y			
		Weather monitoring	Y			Y			Y					
		Site Conditions	Y					Y						
		Hazards					Y							Y
		Health and safety audits	Y	Y	Y	Y		Y			Y	Y		
		Quality inspections	Y	Y	Y	Y		Y	Y	Y				
	Identification	Onsite accounting of operatives						Y	Y	Y				
		Onsite accounting of visitors						Y	Y	Y				
		Tracking plant operations							Y		Y			Y
		HVAC systems maintenance						Y	Y					
		Rebar / materials accounting onsite								Y				
		As built elements (tracking of maintenance reports)	Y						Y					
		Site Equipment						Y		Y				
		Fixed Equipment							Y	Y				

Table 3. 3 Construction processes that could benefit from the use of mobile computing and mobile computing technologies that are appropriate for each process (ARUP, 2003)

Although the potential of mobile computing has been explored through various evaluations, this research has revealed limitations and barriers to mobile computing implementation in construction. Saidi et al. (2002) found two barriers to the use of mobile computing in construction after their experimental research:

- **Limitations of Mobile Computer.** The limitations of mobile computers include screen size, screen visibility, processing capability, and input method.
- **Construction Industry's Characteristics.** The barriers relating to the construction industry's characteristics have been recognised as the physical jobsite conditions (such as temperature, humidity, dust, etc.) and organisational issues such as the industry's fragmentation and low risk tolerance.

From a general perspective, Magdic et al. (2002) examined the whole mobile computing system consisting of mobile computers, wireless networks and mobile construction applications, and pointed out the following existing problems:

- **Limitations of Mobile Computer.** Mobile computers are not suitable under stressful construction site conditions, such as dust, strong light, rain, handling by workers, etc. The limitations in Human Computer Interaction (HCI) restrain users in inputing data into mobile computers and outputting data to users.
- **Wireless Data Transfer Problems.** The wireless data transfer solution of connecting a PDA with a mobile phone results in a connection difficulty between the PDA and the mobile phone. The use of the cell phone network as the wireless data transfer method is limited by the small bandwidth, low data rate, and data transfer delay.

- **Mobile Application Problems.** The tested mobile application – the document management system, needed to be improved via the use of a process model, the requirement of a user-friendly interface and the use of structured information.

The key objective of using mobile computing in construction is to equip on-site users with mobile computers that are easy to use and can interact with software and hardware interfaces and remotely access required construction information under stressful construction site conditions. Key challenges of mobile computing in construction were discussed by Anumba and Obonyo (2003) as follows:

- **Complexity and Cost of Mobile Application Deployment.** The deployment of mobile application systems for construction sectors is very complex and costly, because of the involvement of multiple networks (WWAN, WLAN, WPAN, etc.), multiple operating system platforms (Pocket PC, Windows Mobile, Palm, etc.), multiple devices (Pocket PCs, smart-phones, Pocket PC phones, tablets, etc.) and multiple network protocols (WAP, WiFi, Bluetooth, IEEE 802.11b, etc.). The application deployment is further complicated by arguments over interoperability, data transfer standards, communication bandwidth, security, availability, information security and implementation feasibility. Finally, the testing environments are not easily available.
- **Focus on the User Requirements.** Current deployment of mobile applications is confronted with the situation that systems are designed without a detailed understanding of user's requirements. Many organisations focus on managing the technological perspective rather than the actual construction process that the mobile system will help users to accomplish. Therefore, research should target the context

in which these mobile systems will be used on the construction site and the needs of on-site users.

- **Integration with Existing Applications.** Current mobile applications are designed to perform a specific task such as project, inventory or safety management etc. These solutions are based on multiple technology domains and rigid frameworks that must be centrally managed and hand integrated at the source code level. This situation creates enormous problems in deployment, setting up and configuration. The complexity and heterogeneity result in inconsistent interface, redundancy and out-of-sync information. With the emergence of high speed wireless networks coupled with enhanced processing power and memory capabilities of mobile devices, the web service infrastructure can efficiently extend software systems and applications to the mobile and wireless devices.
- **Content Adaptation.** An important challenge in developing mobile applications is the prioritisation of text and graphics, to fit into the small screen of mobile devices. Adapting content and applications to fit multiple device types and mark-up languages will also be a key challenge in the application development process.
- **Choice of Wireless Technologies.** There is a wide variety of applicable wireless technologies. All of these technologies need to be considered, depending on application requirements and the costs involved. The compatibility and inter-operability between different heterogeneous wireless networks and between wireless networks and the existing ICT infrastructure should also be considered.

The development of mobile computing systems that integrate with current construction site practices should ensure that the Return of Investments (ROI) exceeds the cost of obtaining information wirelessly. Olofsson and Emborg (2004) conducted a series of in-depth interviews with construction personnel to address three aspects including the construction sector in which mobile computing systems can be applied, the economic impact of mobile applications, and the ways in which mobile applications can be introduced in specific operations. After analysing the Return of Investments (ROI) for three scenarios including installations and building services, a road construction project and a ready mixed concrete delivery, they concluded that the benefits of using mobile applications include reduced lead times, more efficient use of resources in the field and enhance quality of work. Figure 3.2 shows the estimated ROI for the concrete delivery scenario, in which the size of the circles is proportional to the estimated total monetary value of the benefits derived and the additional costs incurred.

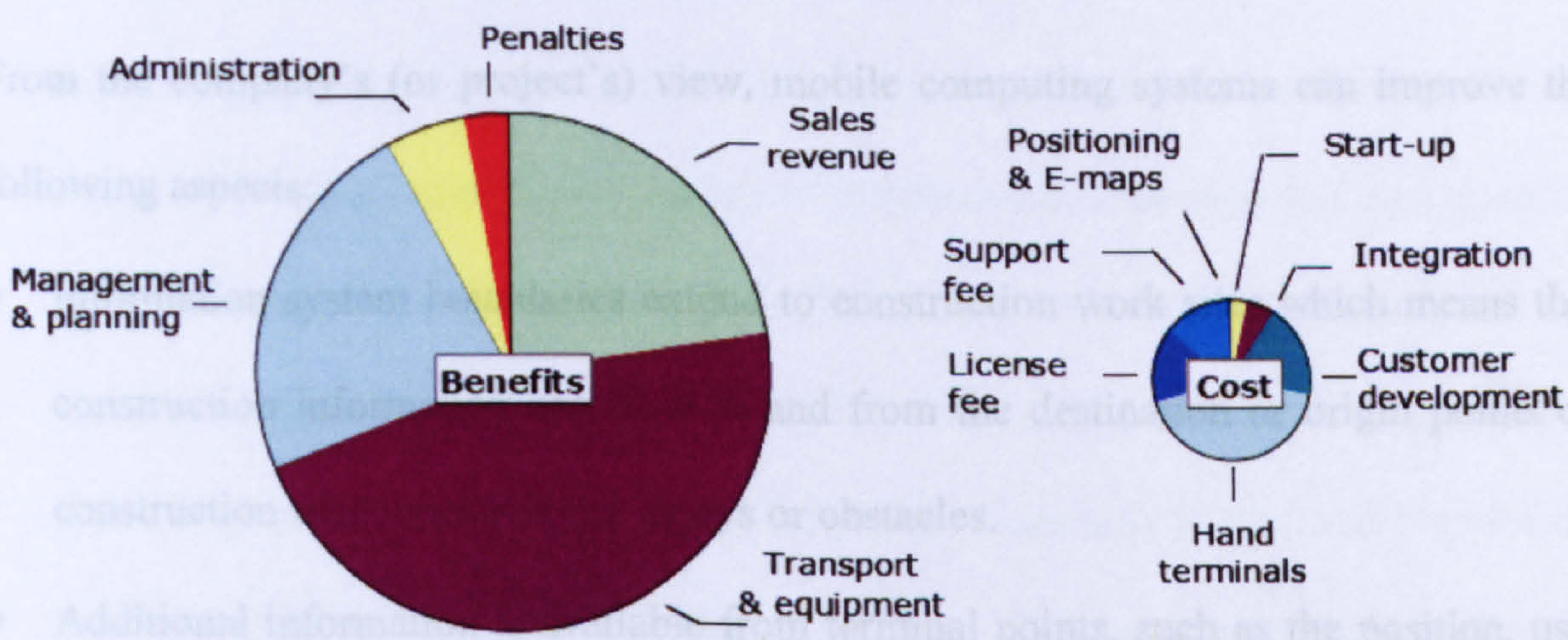


Figure 3. 2 Estimated ROI for concrete delivery. The value added is 4.5 times the additional cost per year (Olofsson and Emborg, 2004)

De la Garza and Howitt (1998) conducted an assessment of wireless data technology and the information needs on construction work sites, and pointed out the following benefits of incorporating wireless communication technology onto construction sites.

- Firstly, the wireless communication technology will permit information to flow in a faster, more timely manner between the field and the trailer. Wireless communication techniques will allow the parties to communicate without leaving their respective locations.

- Secondly, wireless communication has the potential to provide the personnel in the field with information while they are actually performing works.
- Finally, the wireless communication technology can allow the supervisory personnel at a construction site to stay in the field, and hence affect productivity.

Based on the facts that a mobile computer is bound to a specific person, the user's location can become important information, the mobile computer is available anytime and anywhere, and the person can access the system anytime and anywhere, Rebolj et al. (2001) summarised the benefits from two perspectives.

From the company's (or project's) view, mobile computing systems can improve the following aspects:

- Information system boundaries extend to construction work sites which means that construction information can flow to and from the destination or origin points on construction work sites without delays or obstacles.
- Additional information is available from terminal points, such as the position, user ID, device ID etc., which means that terminals can help applications to become context sensitive.

From the individual's view, the improvements include the following issues:

- The user can be available anytime.
- Any other actors in relevant projects are available.

- Personal communication can improve significantly through automatic selection using context-sensitive parameters.

Through the review of previous research, the investigation of case studies and the discussion of future scenarios, Bowden et al. (2006) discussed the areas that can be improved through the use of mobile IT both in the present and the future. These areas are listed as follows:

- **Reduction in construction time and capital cost of construction.** Generic benefits of using mobile computing technology for on-site construction personnel include: the elimination of rewriting/retyping, the reduction in travel time to retrieve information, and the reduction in travel time to view point of activity.
- **Reduction in operation and maintenance costs.** Two areas in which mobile computing can facilitate a reduction in operation and maintenance costs have been recognised as the increasing efficiency of maintenance personnel, and the collection and provision of information throughout the life cycle of a building or structure.
- **Reduction in defects.** Users on construction work sites can use mobile computing technology to collect the data electronically in a uniform format and transfer the collected data back to central database in real time. The database can be searched for trends: reoccurring defects, re-offending subcontractors and delays in rectifying defects, which can then be addressed proactively.
- **Reduction in accidents.** Mobile computing can facilitate a reduction in accidents via the following aspects: to collect and send problem notifications to subcontractors via mobile phone SMS/WAP, to enable workers to report near misses at the point of activity and to improve health and safety on-site via automated construction sites.

- **Reduction in waste.** Construction and demolition commonly include building materials and products such as concrete, asphalt, wood, glass, and metal. In order to reduce waste, the first step is to know what materials and equipment have been delivered. Mobile computing has been used in the construction material supply chains. Examples of mobile computing technologies used to track materials and equipment include the bar-coding technology, RFID tag technology and GPS technology.
- **Increase in productivity.** Construction productivity can be increased through automating tasks and enhancing collaboration. Mobile technologies currently have the capabilities required by automating tasks, such as live two-way voice, video and data transfer. In the area of enhancing collaboration, mobile computing has been introduced to eliminate the paperwork, reduce delays, remove the needless data re-entry and provide up to the minute information.
- **Increase in predictability.** In this aspect mobile computing can provide accurate real-time progress and cost information as the project progresses, and enables communication from the point of the activity back to the rest of the project team. Some existing mobile applications include timesheet, plant utilisation, materials management and progress reporting.

3.10 CONCEPTUAL FRAMEWORK AND ILLUSTRATIVE SCENARIO

This section discusses the outcomes of the literature review conducted, which include the conceptual framework and the illustrative scenario. The conceptual framework demonstrates how mobile computing can be facilitated and be incorporated into the construction information management at different levels in accordance with the operational definition of information management (Section 2.2.2.3). The illustrative scenario represents the potential and forecasts a possible way of applying mobile computing in construction site information management.

3.10.1 THE CONCEPTUAL FRAMEWORK FOR MOBILE COMPUTING IN CONSTRUCTION

The theoretical model of information management that recognises the need to consider information management from different levels provides a possible method to present a structure of the knowledge, research and practices in the area of using mobile computing in construction information management. According to the model, information should be managed at the level of the individual, the system, the context and the environment (Section 2.2.2.3). Information retrieval is concerned with the interaction between the individual and a system or range of systems in order to meet specific information requirements. The systems are designed to enter information, store it and facilitate effective retrieval. The context in which information systems are encountered influences systems design and encompasses the user. The environment surrounding the information context consists of political, legal, regulatory, social, economic and technological forces.

Through the review of mobile computing in construction (Section 3.9), the focuses of research and practices in this area can be viewed from different levels based on the model of information management. At the individual level, because of the restriction of input and output methods, challenges to access, processing and modifying large amounts of information on mobile computers should be addressed from the perspective of HCI (Human Computer Interaction) design. Kondratova (2004) stated that because the widespread usage of mobile devices is limited by antiquated and cumbersome interfaces, speech recognition along with VoiceXML technology can be applied to overcome user interface limitations for mobile computers and improve their usability for construction site applications. Garrett and Sunkpho (2000) pointed out one of the key issues in delivering mobile IT systems on sites is to provide a useful and usable interface between the field worker and the computing support. Some interfaces include the attachable keyboard or pointing devices, speech recognition and speech synthesis, wearable devices, pen-based devices, and other "post-interface" devices, such as eye-tracking or lip-reading. The benefits of the World Wide Web can be enhanced through the use of mobile computers to access Web content. However, the use of mobile computing for accessing Web content are limited by some problems, such as bandwidth limitations, screen real-estate shortage, battery capacity and the time costs of pen-based search keyword input. Buyukkokten et al. (2000) provided a Power Brower technology for mobile computers, which addressed bandwidth and battery life limitations by providing local site search facilities for all Web sites and addressed the keyword input problem by providing site specific keyword completion and indications of keyword.

At the system level, through the integration of mobile computers, wireless networks and mobile applications, current developments of mobile computing systems aim to meet the information requirements of construction organisations and individuals, support on-site information retrieval and collection, support their decision making on construction sites, and channel the construction information into their strategic planning process. For examples, the SHERPA (Stent Handheld ElectRonic Piling Assistant) system enables on-site construction personnel to share real-time piling information via mobile computers accessing a centrally site-located database through a wireless local area network (Ward et al., 2003). In order to assist construction managers to manage different types of information, Kimoto et al. (2005) developed a mobile computing system for the management of information on construction sites. This mobile computing system contains four sub-systems including the inspection system, checklist and reference system, position check system, and progress monitoring system.

At the context level, research focuses on the identification of construction processes that can be improved from the use of mobile computing, the evaluation of barriers and challenges when applying mobile computing in real construction projects, and the benefits that the implementation of mobile computing can provide to construction organisations. The COMIT (Construction Opportunities for Mobile IT) project (ARUP, 2003) identified construction processes that could benefit from the use of mobile computing and mobile computing technologies that are appropriate for each process. These construction processes include three main categories: on-site communications, data capture and identification processes. The benefits that mobile computing can provide include the reduction in construction time and capital cost of construction, the reduction in operation and maintenance costs, the reduction in defects, the reduction in accidents, the reduction in waste, the increase in productivity, and the increase in predictability (Bowden et al., 2006). However, the challenges of using mobile computing in construction should be clearly understood in order to address them before the wide adoption of mobile computing by construction organisations. The key challenges include the complexity and cost of mobile application deployment, the focus on user requirements, the integration with existing applications, the adaptation of different information content, and the choice of wireless technologies.

From the analysis of related research literature, it therefore can provide a conceptual framework that presents a structure of the knowledge, research and practices in the area of using mobile computing in construction information management. This framework can demonstrate how mobile computing can be implemented at each level to manage construction information and can identify some factors that have an influence over the way mobile computing can be applied in construction, see Figure 3.3 (Chen and Kamara, 2005a).

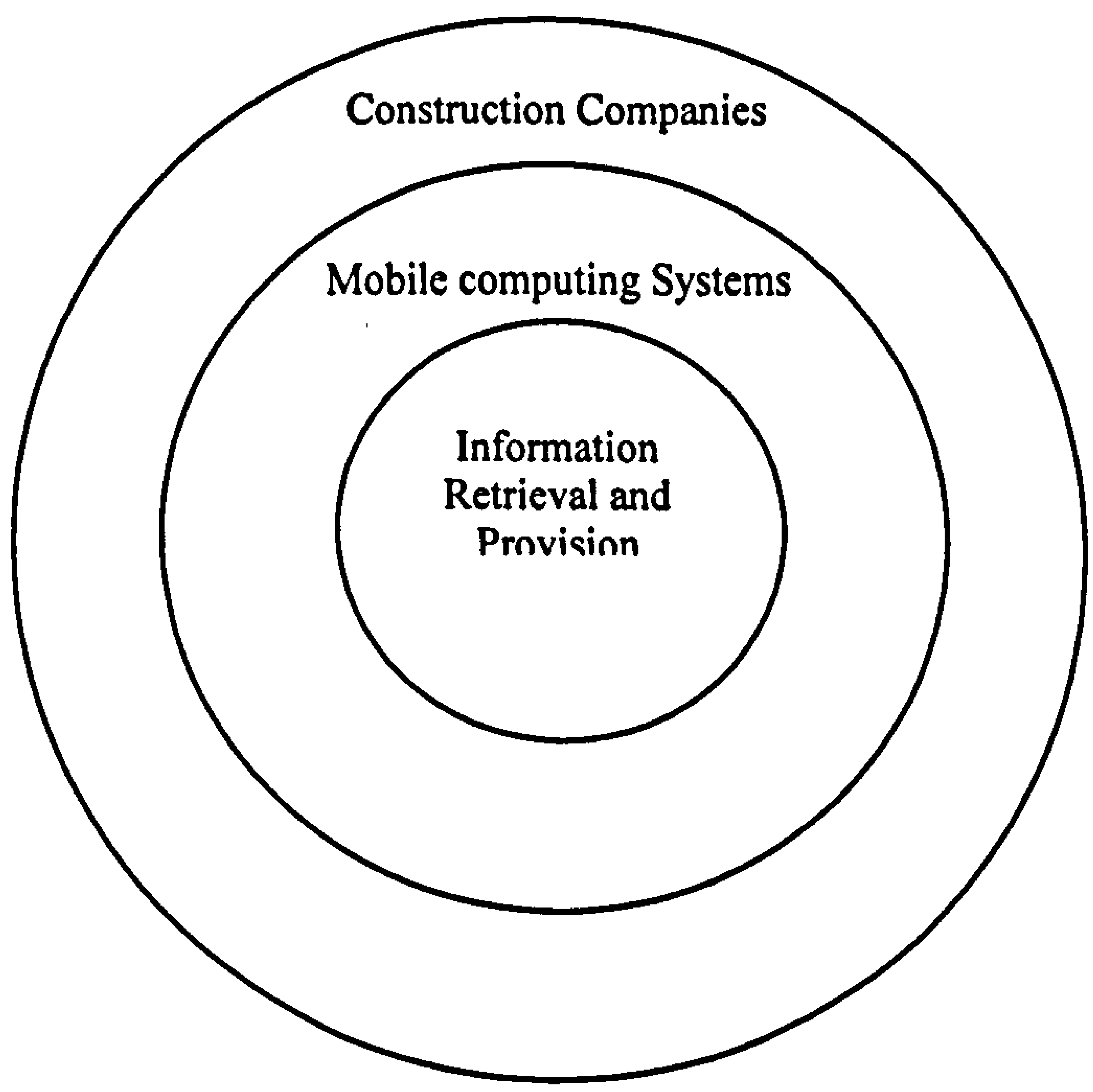


Figure 3. 3 A conceptual framework for using mobile computing in construction information management

The terms used in this framework are explained and discussed as follows:

- *Information retrieval and provision* is concerned with the use of mobile devices by construction individuals to retrieve information from or provide information to systems or sources with a view to meeting specific construction information requirements. On the one hand, project management and design information can be delivered just in time to jobsite users (foreman, supervisor, project manager, engineer, inspectors etc.) with the interaction between mobile devices and selected information sources. On the other hand, construction users on their jobsites can capture and transmit real time data to back-end systems, and keep information sources up-to-date. The level of information retrieval and provision might have three main components: indexing and search languages, human computer interface design, and training and education. Indexing and search languages should be designed to be more effective and easy to use because of the limitation of the computer processing capability of mobile devices and the complex construction jobsite environment in which users find it difficult to input long search key words or find information from a complex index. The most important factor that constrains the wide use of mobile devices is the restrictive input/output interface such as the small screen size and slow text input facilities. Elements considered in mobile device Human Computer Interaction design include textual input reducing, database, interactive tables, user action supporting, dynamic interface, and graphical results. As a new technology, education or training courses are necessary for construction users to understand the process to use mobile computing information systems.

- *Mobile computing systems* are designed to collect, store, process and retrieve information in a wireless communication environment. Facilities to support efficient and accurate wireless data collection and information retrieval should be coupled with adequate physical storage capacity and appropriate logical database structures. Mobile computing systems that have three components of mobile devices, wireless networks, and wireless technologies, are the invisible tools supporting wireless data communication and information services. The operation of mobile computing systems cannot only exist on an isolated, individual level, but rather in an integrated and systematic way, which means mobile computing systems should combine with existing information systems. The organised and integrated systems meet the requirements for construction organisations and individuals to create and collect construction information, retrieve information to support their decision making, channel the construction environment information into their strategic planning process, and summarise information for different groups of workers and managers within their organisation.

- *Construction Companies* are the contexts that encounter mobile computing systems and have an impact on the systems design. Construction companies in which mobile computing systems, coupled with other systems, operate determine the functions and requirements that these systems can be expected to perform. On the other hand, the ability of mobile computing systems to perform or record transactions and achieve more flexible information communication may change the construction companies such that the functions and information requirements that need to be performed change. Therefore, those opportunities offered by mobile computing systems have affected the way in which construction companies operate and are influencing both internal communication and external communication with suppliers, contractors, subcontractors, and clients. This means the advantages of mobile computing are dependent on whether business processes in construction companies have been changed in any way to maximize the impact of mobile computing. Business process re-engineering (BPR) is the technique to align business strategy, business objectives, and key business processes with the new information technology – mobile computing. Additionally, this level of the conceptual framework should also concern construction companies' soft issues such as company culture and history, users' knowledge and experience, education and training, and users' values and beliefs.

Table 3.4 shows the further development of this framework to identify the construction information processing agent on each level, and the links between the levels and the different perspectives on the definition of information concept. Information processing agents normally include construction individuals who use mobile devices to retrieve or collect information, systems that provide wireless information communication and services, and companies that determine system functions and organisational information requirements. Links between the levels and the perspectives of information definition are also identified in this table.

Level	Information Processing Agent	Information Definition	Construction Information
Information Retrieval and Provision	Construction Individual	Information as knowledge	Procurement information, Project management information, Site management information, Administrative information
Mobile Computing Systems	System	Information as data / Information as thing	Request for information, Materials management information, Equipment management information, Cost management information, Jobsite record, Submittals information, Safety information, QC/QA, Future trends
Construction Companies	Company	Information as a resource	Technical information, Commercial information, Management and Control information

Table 3. 4 Level definitions of construction information processing and management

The conceptual framework provides a general consideration for applying the new emerging technology for the management of information in the construction industry. Because the nature of the industry is highly fragmented and information-intensive, there is a need to increase the efficiency of exchanging massive volumes of information at high speed and at relatively low cost. The increasing use of mobile technologies will give the construction industry a powerful potential to increase efficiency and effectiveness of information flow and therefore to streamline construction processes.

The conceptual framework demonstrates how the concept of information management and mobile computing can be integrated together, and how mobile computing can be applied at each level of information management. Factors of applying mobile computing at each level and relationships between each level are also identified and explained in the conceptual framework. At the information retrieval and provision level, the end-user is the construction individual who uses mobile devices to perform information processing, and the purpose of the whole information system is to meet the individual's information requirements. Factors at this level that should be concerned by construction companies include indexing and search languages, human computer interface, and training and education for jobsite users. The level of mobile computing systems in which information processing and communication take place is the core level in this framework and consists of mobile devices, wireless networks and wireless technologies, which support wireless information services. The integration of the mobile computing system with other information systems should be the concern of system designers at this level. Functions and information requirements of mobile information systems are determined by construction companies, and business processes should be improved through business process re-engineering in order to maximise the benefits of using mobile computing.

3.10.2 THE SCENARIO OF USING MOBILE COMPUTING ON CONSTRUCTION SITES

In order to illustrate the potential and forecast a possible way of applying mobile computing on construction sites, the following example scenario (Chen and Kamara, 2005b) within the construction context will demonstrate some key concepts of mobile computing and pervasive computing, and describe how construction personnel can work in an environment with mobile computing.

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

At first glance, this scenario seems like a fiction rather than reality, but it is surprising that all the component technologies actually exist today. The hardware technologies such as PDA, wireless networks and software-controlled appliances, and the software technologies including location tracking, online weather forecasting, online calendars and speech recognition, are presently all available. It looks like a fiction because the systematic integration is much better than the sum of the individual components. Additionally, this scenario embodies many new concepts of pervasive computing and importantly presents a new way to think about computers and users.

As introduced in the previous section, the major difference between mobile computing and pervasive computing is the *proactivity*. In this scenario proactivity has been illustrated in many instances: transferring the schedule of concrete foundation walls to David's PDA when the system detects he is going to Field A, sending an email to the supplier after the delay is confirmed, suggesting David to check heavy equipment safety after reviewing his calendar and calculating the walking back time, and transferring the updated schedule to the presentation computer. However, a proactivity system may offer some suggestions or functions that are useless to users or annoy users. Therefore, another major ability of pervasive computing is that the system should precisely track *user intent*. Within this scenario, before transferring the schedule to David's PDA, the system knows exactly that his intent is to check the progress of concrete foundation walls.

In order to precisely track user's intent, the key issue for pervasive computing is the *context awareness*, which is implied by the environment surrounding a particular user. Abowd and Mynatt (2000) suggested the "five W's" including who, where, what, when and why, which compose a necessary context environment. The "who" element currently focuses on the identity of one particular user, for example David is the project manager in this scenario. The position or location can be recognised as the "where" context, such as David is going to Field A. The "what" factor takes account of the user's behaviours or activities, such as David checking the construction progress. The meanings of "when" have three aspects: using time as an index into a captured record, summarising how long a user has been at a location, and understanding relative changes in time. Why a particular user doing it is more difficult and challenge for pervasive computing than knowing what he is doing, since it needs other contextual information to be analysed. The concept of "context-aware" is the ability of a pervasive computing system to adjust or modify its behaviour by perceiving the information of the user's state and surroundings. There are two main ways to obtain context information: from the user's personal computing space and from the user's environment (Satyanarayanan, 2001). The user's computing space may consist of personal calendars, address books, contact lists, and to-do lists. Information that can be obtained in real time from the user's surroundings includes position, other users nearby, and locally observable objects and actions. In the above scenario, the reason why the system knows David's intention is to check the progress of concrete foundation walls is because the pervasive computing system knows he is project the manager (Who) from his login to the system; he is going to Field A (Where) from the location tracking system; and he will check the construction progress (What) in the morning (When) from his calendar.

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

3.11 PROBLEM ANALYSIS

Mobile computing includes three major components: mobile computers which can be used indoors and outdoors while the user is in motion, wireless networks with sufficient bandwidth which can be accessed while in motion, and mobile applications supporting context-sensitivity and personalisation (Rebolj and Menzel, 2004). The details and features of mobile computing technologies have been introduced in Sections 3.4, 3.5 and 3.6. Because the construction industry has its own specific characteristics, including the involvement of various project partners, the separation between site offices and work sites, and the mobility of construction personnel; mobile computing has the potential to increase the effective use of IT in an integrated and holistic way. However, mobile computing technologies that can be implemented to solve particular problems in construction need to be evaluated and potential areas that can be improved by using these technologies need to be identified. Research that focuses on technologies can be considered as the "technology push" method that evaluates what mobile computing technologies can offer and finds a problem it can solve, which seems appropriate for a problem in the industry. Examples include the evaluation of IP Telephony technology for construction information communication and the integration of PDAs and bar code scanning for construction supply chain management.

Efficient communication systems are important for the improvement of information transmission speed between the site office, headquarters and the supply chain. However, traditional circuit-switched based telecommunication systems are expensive and their coverage may not reach remote areas of construction sites. This situation leads to the evaluation of Internet Protocol Telephony technology that is cheaper, rapidly deployable and more efficient, and an investigation into its potential use in construction (Beyh and Kagioglou, 2004). Benefits that IP Telephony can offer to construction information communication include the integration of all types of contact streams (voice, data, fax and video) onto a single network, providing a platform for productivity-enhancing applications, the reduction of line charges, network costs and IT expenses, and simple operations management.

Construction supply chain management aims to minimise the time taken to perform construction activities, eliminate waste, and to enhance dynamic control by connecting involved participants to reduce construction conflicts and project delays. In construction projects, most initial construction data come from the construction work site, which is an extension of the construction supply chain. The effective acquisition of accurate data from work sites has a major influence on the performance of supply chain management systems. However, on-site construction personnel usually use paper-based documents, drawings, contracts and specifications, which is time consuming and reduces the performance of project management in information acquisition. Meanwhile, paper-based documents of site processes are ineffective and cannot obtain quick responses from the project control centre. The integration of Personal Digital Assistants (PDA) and bar code scanning can be used in several construction processes and provides cost savings through increased speed and accuracy of data entry, so that the effectiveness and convenience of information flow in construction supply chain management systems can be improved (Tserng and Dzeng, 2005). The supply chain management system that integrates PDAs, bar code scanning and web portals enables on-site individuals to update and upload collected data immediately to the supply chain web portal. Then, suppliers and sub-contractors can receive real-time project-related information and make better decisions for the future management and control of the project.

According to the research on mobile computing technologies, the technologies have the potential to solve some existing problems in construction and can improve the efficiency of information communication on construction sites. However, because of the complex features of construction project and the diversity of mobile computing technologies, it is essential to test and examine these technologies on real construction sites and ensure they become more consistent and reliable before construction companies can widely adopt them in their daily work. The research includes the evaluation of mobile computer and examination of wireless networks.

Previous research into using mobile computers on construction sites has shown that only when mobile computers which satisfy the following criteria are accepted by construction users on construction sites: the screen must be visible in bright sunlight, the battery life should be able to support user's on-site time, the device must resist being dropped onto a hard surface, and be able to be used in the rain (Elzarka et al, 1997). However, if mobile computers are to become widely accepted further research is needed into the acceptability or usability of such devices in terms of how easy construction personnel find their use on construction work sites. Research into usability testing of mobile computers on construction sites (Bowden et al., 2003) investigated the views of construction personnel about the use of mobile computers on sites and compared different commercially available devices. The results from the usability testing illustrated that there were no significant differences across job type in either preference for using the device or satisfaction with using the device and the majority of the participants would be happy to use a mobile computer on construction sites because it is "very powerful" and they "definitely see an advantage". However, the barriers of cost and training concern users and they require proof that the devices would be cost-effective, and that usable, useful applications would be available.

Wireless networks are able to deliver real-time information and serve as the 'last mile' from a network connection within the main information system to the desired location on work sites. However, construction information comes in various types, each of which has different features in terms of size, format, timing, and importance. Meanwhile, the capability of transferring information from each type of wireless network depends on their bandwidth, delay, and data rate. It is important to assess the extent to which wireless data technology can fulfil the information needs on construction sites. De la

Garza and Howitt's research (1998) provided a useful attempt to examine whether wireless networks could transfer on-site construction information. Their research identified on-site information with a focus on type, amount, quality and timeliness; investigated wireless data communication technologies with a focus on data rate, bandwidth, service requirements and cost; and finally compared different wireless networks with the consideration to meet different information transfer requirements. They concluded with three primary considerations when using wireless technology on construction sites: information security, the potential for electromagnetic interference to other on-site equipment, and the interaction among signals resulting from transmitting in a cluttered environment.

Although mobile computing can be used to improve the efficiency of information communication on construction sites and has been assessed in a site environment, the potential for mobile computing has not been fully exploited for the construction industry, and mobile computing technologies are not broadly adopted by construction companies. Therefore, it is essential to clearly identify what areas can be improved from the implementation of mobile computing and how mobile computing can benefit the construction industry. After a comparison of tradition construction tasks and the same tasks with the introduction of mobile computers, Saidi et al. (2002) identified construction tasks that are suited for applying mobile computing and those that are not suited. Generally, construction tasks that require access to text information, viewing a small detail of a document, the entry of binary data, the entry of data into a form or instant transfer of information, are suitable for mobile computing. On the other hand, tasks that require complex computing, a "big-picture" view of a document, a constant connection to networks, lots of manual data entry, or under tough environment, are not suitable for the application of mobile computing. Compared with Saidi's research that focuses on the identification of construction tasks, the COMIT research project (ARUP, 2003) aims to provide an indication of which mobile computing technologies would be appropriate for each of the construction processes that could benefit from the use of mobile computing. These processes are generally communication processes, data capture processes and identification processes. The detailed links between these processes and applicable technologies are presented in Table 3.3.

In order to convince construction companies to use mobile computing technologies, the development of mobile computing systems should ensure that Return of Investments (ROI) exceeds the cost of obtaining information wirelessly. Olofsson and Emborg (2004) conducted a series of in-depth interviews to investigate the Return of Investments from the three aspects of the construction sector in which mobile computing can be applied, the economic impact of mobile computing, and the ways that mobile computing integrates in specific operations. They concluded that the benefits of using mobile computing include reduced lead times, more efficient use of resources in the field and enhanced quality of work. In order to increase the awareness and convince more construction personnel to realise the benefits of using mobile computing in construction, Bowden et al. (2006) conducted a number of case studies which involved construction personnel using mobile devices to resolve specific construction problems and summarised the areas that can be improved through the use of mobile IT both in the present and the future. These areas include a reduction in construction time and capital cost of construction, reduction in operation and maintenance costs, reduction in defects, reduction in accidents, reduction in waste, increase in productivity, and increase in predictability.

As a potential technology, mobile computing is becoming a major research theme in the domain of Information Technology in Construction. However, most research in this area focuses on a detailed aspect or single facet of mobile computing. Examples include the "technology push" method that evaluates what a single mobile computing technology can offer and finds a problem it can solve, the test of using mobile computers on sites, and the examination of wireless networks transferring construction information. As one technology can be widely adopted in the industry, the general concept of the technology and the interrelationship between the technology and the industry should be identified and explicated. However, the key factors that can affect the use of mobile computing in construction and the links between mobile computing and on-site information management are not clearly identified and not comprehensively presented. Therefore, a detailed framework that includes those factors and interrelationships is necessary to provide guidance on the effective development and implementation of mobile computing for on-site information communications.

3.12 SUMMARY

This chapter reviewed technologies of mobile computing with the introduction of commercially available products and the relevant research that has been conducted within the area of mobile computing in construction. The review of previous research aimed to provide a knowledge foundation from which to learn and to ensure the research conducted for this thesis adds to rather than duplicates existing or other ongoing works. The outcomes of this literature review consisted of the conceptual framework and the scenario.

CHAPTER 4

RESEARCH METHODOLOGY AND RESEARCH UNDERTAKEN

4.1 INTRODUCTION

This chapter briefly introduces the philosophical framework within which this research has been conducted, the methodological considerations including the research methodology for ITC (IT in Construction), the choice of appropriate methodology and the selection of detailed research methods. It then explores the reasoning behind the methodology selected for this research project and discusses the overall research design. Finally, this chapter presents the research undertaken to meet the aim and objectives of the thesis.

4.2 THE NEED OF APPROPRIATE METHODOLOGY

As stated in Chapter 1, the aim of the research is to explore how mobile computing technologies can be implemented in construction site environments to manage on-site information. The specific objectives of the research are:

1. to investigate the concept of construction information management;
2. to investigate the state of art of mobile computing technologies and their practices in the construction industry;
3. to develop a framework to explore the use of mobile computing in construction site information management; and
4. to demonstrate the validity of the framework through an illustrative example.

In order to achieve the research aims and objectives, the research strategy should be appropriately designed in accordance with the subject under investigation., Firstly, because philosophical assumptions about human nature and how society is conceptualised are directly related to the selection of research methodology, and because research instruments and methods used by research are operated within a set of assumptions, it is necessary to discuss those assumptions explicitly and the research paradigm adopted should be made apparent. Secondly, according to the context of the research, research methodologies for the area of information technology in construction should be investigated and a review of various research methods is essential before designing the research strategy for this research. Finally, based on the nature of research objectives, research methods for each research question should be appropriately selected with the arguments of their advantages and disadvantages presented.

4.3 PHILOSOPHICAL FRAMEWORK

The philosophical assumptions about human nature and how society is conceptualised are directly related to the selection of research methodology. Hughes (1993) stated that "research instruments and methods cannot be divorced from theory; as research tools they operate only within a given set of assumptions about the nature of society, the nature of human beings, the relationship between the two and how they may be known". However, these 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 and Baroudi, 1991).

Although the philosophical assumptions were not defined at the start of this research, the research instruments and methods used by the researcher are operate within a set of assumptions. In order to enhance the logic inherent for the research, the nature of the phenomenon under investigation and the research paradigm adopted should be made apparent. Therefore, the philosophical framework within which the research has been conducted is introduced and discussed in the following sections.

4.3.1 PHILOSOPHY OF SCIENCE

Smith (2000) defined that the philosophy of science is concerned with four major questions:

- What characteristics distinguish science from non-science?
- What procedures should scientists follow?
- What conditions must be satisfied for a scientific explanation to be correct?
- What is the cognitive status of scientific laws and principles?

He then stated that the philosophy of science as a discipline is related to other areas including:

- *the history of science* – how science has actually developed, whatever the 'ideal' science might do;

- *the sociology of knowledge* – how social structures and institutions, scientific societies and journals and the social networks of individual scientists affect the growth of science;
- *the psychology of research* – how individual scientists develop ways of thinking about and interpreting the world; pressures for conformity and bursts of creativity.

The origin of the philosophy of science can be traced back to the ancient Greeks. Aristotle (384-322 BC) established the foundation of speculating about 'the nature of things' and particularly provided the 'inductive-deductive' view for the development of knowledge as shown in Figure 4.1. Losee (1993) discussed Aristotle's 'inductive-deductive' view and stated that "scientific explanation thus is a transition from knowledge of a fact (point 1 in the diagram) to knowledge of the reasons for the fact (point 2)".

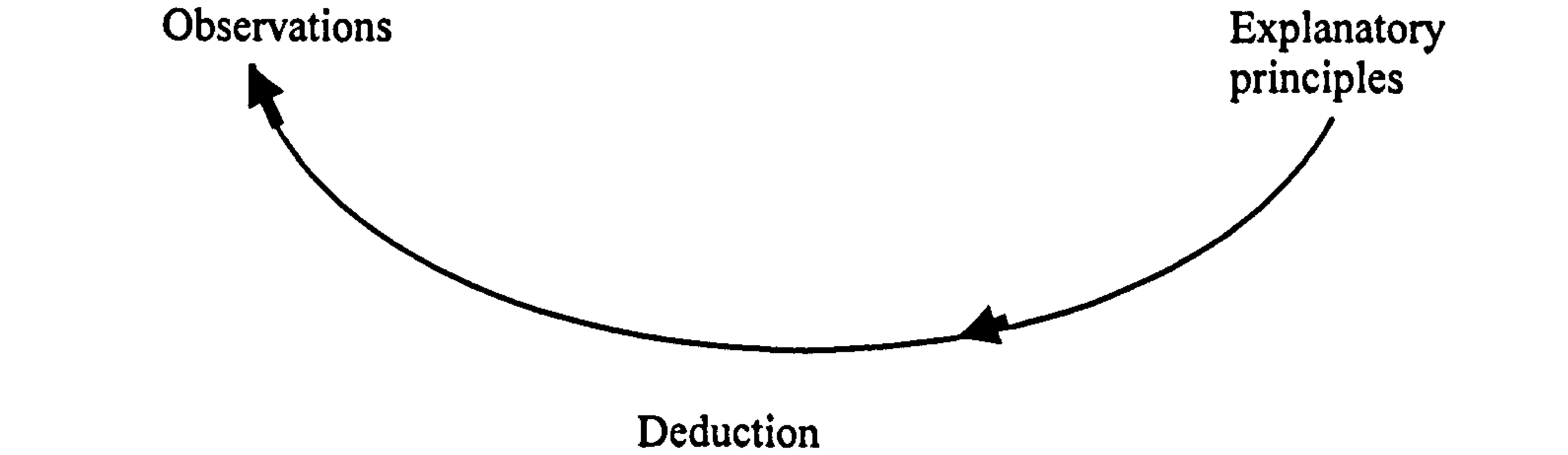


Figure 4. 1 Aristotle's inductive – deductive method (Losee, 1993)

As the development of the philosophy of science, Aristotle's view leads many critical scrutinises. From a historical perspective, Smith (2000) reviewed the significant view points of several key philosophers of science and discussed some questions such as how the traditional sciences work, whether social scientists then apply these methods, modify them, or reject them. The key philosophers of science and their views are provided as follows:

- **The traditional 'inductivist' view of Mill.** John Stuart Mill's (1806-1873) argument as an example argued that there were four primary inductive methods including agreement, difference, concomitant variations and residues, which could be used. The process of inference and induction also could lead people to deduce causal relations. Mill's work described the 'traditional' or 'inductivist' view of the scientific method, which stated that science proceeds by collecting factual data through observation and by experimentation which aims to increase the data base of observation. The generalisations and causal laws could be completely verified if all the deductions from them were correct. There are two conclusions about the traditional view: '*hypothesis follows observation*' and '*we can achieve completely verifiable true theories*'. However, few modern philosophers of science accept these conclusions.
- **The Hypothetico-deductive view of Popper.** Karl Popper (1902-1994) is one of the philosophers of science to attack the traditional 'inductivist' view and creates the hypothetico-deductive method. Popper stated that 'science and knowledge progress by advancing hypotheses, making deductions from them and using observations and experiments continually to test these deductions until they are falsified; then revising or changing the hypothesis to cope with this', which clearly declare 'hypotheses come first and observations follow; observations are interpretations in

the light of theories'. The final crucial point about Popper's view is that 'theories cannot be proved, but can be falsified and falsifiability is the criterion separating science from non-science', which addresses the question of what characteristics distinguish science from non-science.

- **Alternative views of Kuhn.** Popper's views have also been criticised by other philosophers of science. Kuhn (1922-1998) is one of the major protagonists, who agreed with Popper in seeing observation as 'theory laden' and science as a problem-solving activity which cannot be absolutely verified to truth, but he disagreed about the role of falsifiability and the criteria demarcating science and non-science. Kuhn's criterion about demarcating science and non-science is that science is a problem-solving activity with an accepted paradigm. He declared 'To be accepted as a paradigm, a theory must seem better than its competitors, but it need not, and in fact never does, explain all the facts with which it can be confronted'.
- **Views of Lakatos.** Imre Lakatos (1922-1974) provided the compromise between the positions of Popper and Kuhn by keeping Popper's ideas of scientific progress and retaining Kuhn's insights into how science actually changes. He distinguished three types of falsificationism in science: dogmatic falsificationism, naïve methodological falsificationism and sophisticated methodological falsificationism. The key concept of Lakatos's was the 'scientific research programme' that refers to a research programme encompassing a set of theories and methods which can change over time. However, Lakatos declared that there is a 'hard core' of very basic theoretical assumptions that do not change. Within this concept, the 'hard core' would defend them vigorously ('negative heuristics'), but would generate a range of 'auxiliary hypotheses' that are tested for their range and explanatory power ('positive

heuristics'). These 'positive heuristics' are the complement of the 'negative heuristics' used to protect the hard core assumptions.

4.3.2 INFORMATION SYSTEM RESEARCH PARADIGM

A paradigm is the theoretical framework that includes a system by which people view events. The importance of paradigms is that they operate to determine not only what views are adopted, but also the approach to questioning and discovery (Fellows and Liu, 1997). Philips (1987) stated that 'a scientist will normally work within a theoretical framework – a paradigm – that determines the problems that are regarded as crucial, the ways these problems are to be conceptualised, the appropriate methods of inquiry, the relevant standards of judgment, etc.'

The conduct of Information Systems (IS) research is guided by a research paradigm comprising ontological, epistemological and methodological assumptions that together frame the nature of the research and the role of the researcher in the scientific inquiry (Khazanchi and Munkvold, 2003). The term 'paradigm' has the following dimensions:

- **Ontology.** Ontology refers to the theory or study of existence (being), the nature of the world around us, and particularly the slice of reality which the researcher chooses to address. For example, ontological assumptions in the conduct of inquiry within a paradigm might specifically characterise the nature of reality.
- **Epistemology.** Epistemology refers to the theory of knowledge that deals with the nature of knowledge, its scope, and provides a set of criteria for evaluating knowledge claims and establishing whether such claims are warranted.
- **Methodology.** Methodology refers to a procedure by which knowledge is to be generated.

Each of the three dimensions constitutes a set of assumptions or beliefs that '...delineate a way of seeing and researching the world' (Chua, 1986). Chua (1986) classified these assumptions or beliefs into three categories: (i) beliefs about the phenomenon or "object" of study; (ii) beliefs about the notion of knowledge; and (iii) beliefs about the relationship between knowledge and the empirical world. Orlikowski and Baroudi (1991) further discussed the sets of beliefs in each category as follows:

- **Beliefs about the phenomenon.** Ontological assumptions deal with the essence of phenomena under investigation in terms of whether 'the empirical world is assumed to be objective and hence independent of humans', or 'subjective and hence having existence only through the action of humans in creating and recreating it'. There are two types of beliefs: beliefs about human rationality that deals with the intentions ascribed by various researchers to the humans they study, and beliefs about social relations about how people interact in organisations.
- **Beliefs about knowledge.** Epistemological assumptions concern the criteria of how valid knowledge about a phenomenon may be constructed and evaluated. Methodological assumptions deal with which research methods are considered appropriate for gathering valid empirical evidence. The selection of appropriate methods depends on how the veracity of a theory is established.
- **Beliefs about the relationship between knowledge and the empirical world.** Beliefs about the relationship between knowledge and the empirical world consider the role of theory in the world of practice, and reflect the values and intentions researchers bring to their work. The beliefs of researchers have to be suitable to accomplish their research works and the research results they intend to achieve with a given research study.

The paradigm of IS research typically concentrates on the dichotomies at each dimension of assumptions, and the dimensions constitute a hierarchy where higher-level assumptions define the possible scope of the assumptions at lower levels. Fitzgerald and Howcroft (1998) summarised the main dichotomies characteristic of each research tradition and grouped these dichotomies in the following dimensions: paradigmatic, ontological, epistemological, methodological and axiological, see Table 4.1. Khazanchi and Munkvold (2003) argued that the fourth level termed the 'axiological' level in Fitzgeral and Howcroft's research should not be seen as conflicting goals and that relevance does not imply that research needs to be carried out in a less rigorous fashion. Therefore, Khazanchi and Munkvold set up three dimensions in the hierarchy and listed the major dichotomies related to each dimension, see Figure 4.2. One note should be acknowledged that the dichotomies at each dimension represent the extremes of a set of continuums, and in reality the position exists somewhere between these limits.

PARADIGM LEVEL	
Interpretivist No universal truth. Understand & interpret from researcher's own frame of reference. Uncommitted neutrality impossible. Realism of context important	**Positivist** Belief that world conforms to fixed laws of causation. Complexity can be tackled by reductionism. Emphasis on objectivity, measurement and repeatability.
ONTOLOGICAL LEVEL	
Relativist Belief that multiple realities exist as subjective constructions of the mind. Socially-transmitted terms direct how reality is perceived and this will vary across different languages and cultures.	**Realist** Belief that external world consists of pre-existing hard, tangible structures which exist independently of an individual's cognition.
EPISTEMOLOGICAL LEVEL	
Subjectivist Distinction between the researcher and research situation is collapsed. Research findings emerge from the interaction between researcher and research situation, and the values and beliefs of the researcher are central mediators.	**Objectivist** Both possible and essential that the researcher remain detached from the research situation. Neutral observation of reality must take place in the absence of any contaminating values or biases on the part of the researcher.
Emic/Insider/Subjective Origins in anthropology. Research orientation centred on native/insider's view, with the latter viewed as the best judge of adequacy of research	**Etic/Outsider/Objective** Origins in anthropology. Research orientation of outside researcher who is seen as objective and the appropriate analyst of research
METHODOLOGICAL LEVEL	
Qualitative Determining what things exist rather than how many there are. Thick description. Less structured & more responsive to needs & nature of research situation	**Quantitative** Use of mathematical & statistical techniques to identify facts and causal relationships. Samples can be larger & more representative. Results can be generalised to larger populations within known limits of error
Exploratory Concerned with discovering patterns in research data, & to explain/understand them. Lays basic descriptive foundation. May lead to *generation* of hypotheses	**Confirmatory** Concerned with hypothesis testing & theory verification. Tends to follow positivist, quantitative modes of research
Induction Begins with specific instances which are used to arrive at overall generalisations which can be expected on the balance of probability. New evidence may cause conclusions to be revised. Criticised by many philosophers of science, but plays an important role in theory/hypothesis conception.	**Deduction** Uses general results to ascribe properties to specific instances. An argument is valid if it is impossible for the conclusions to be false if the premises are true. Associated with theory verification/falsification & hypothesis testing
Field Emphasis on realism of context in natural situation, but precision in control of variables & behaviour measurement cannot be achieved	**Laboratory** Precise measurement & control of variables, but at expense of naturalness of situation, since real-world intensity & variation may not be achievable
Idiographic Individual-centred perspective which uses naturalistic contexts & qualitative methods to recognise unique experience of the subject	**Nomothetic** Group-centred perspective using controlled environments & quantitative methods to establish general laws
AXIOLOGICAL LEVEL	
Relevance External validity of actual research question & its relevance to practice vital, rather than constraining the focus to that researchable by 'rigorous' methods	**Rigour** Research characterised by hypothetico-deductive testing according to the positivist paradigm, with emphasis on internal validity through tight experimental control and quantitative techniques

Table 4. 1 The major dichotomies in IS research (Fitzgerald and Howcroft, 1998)

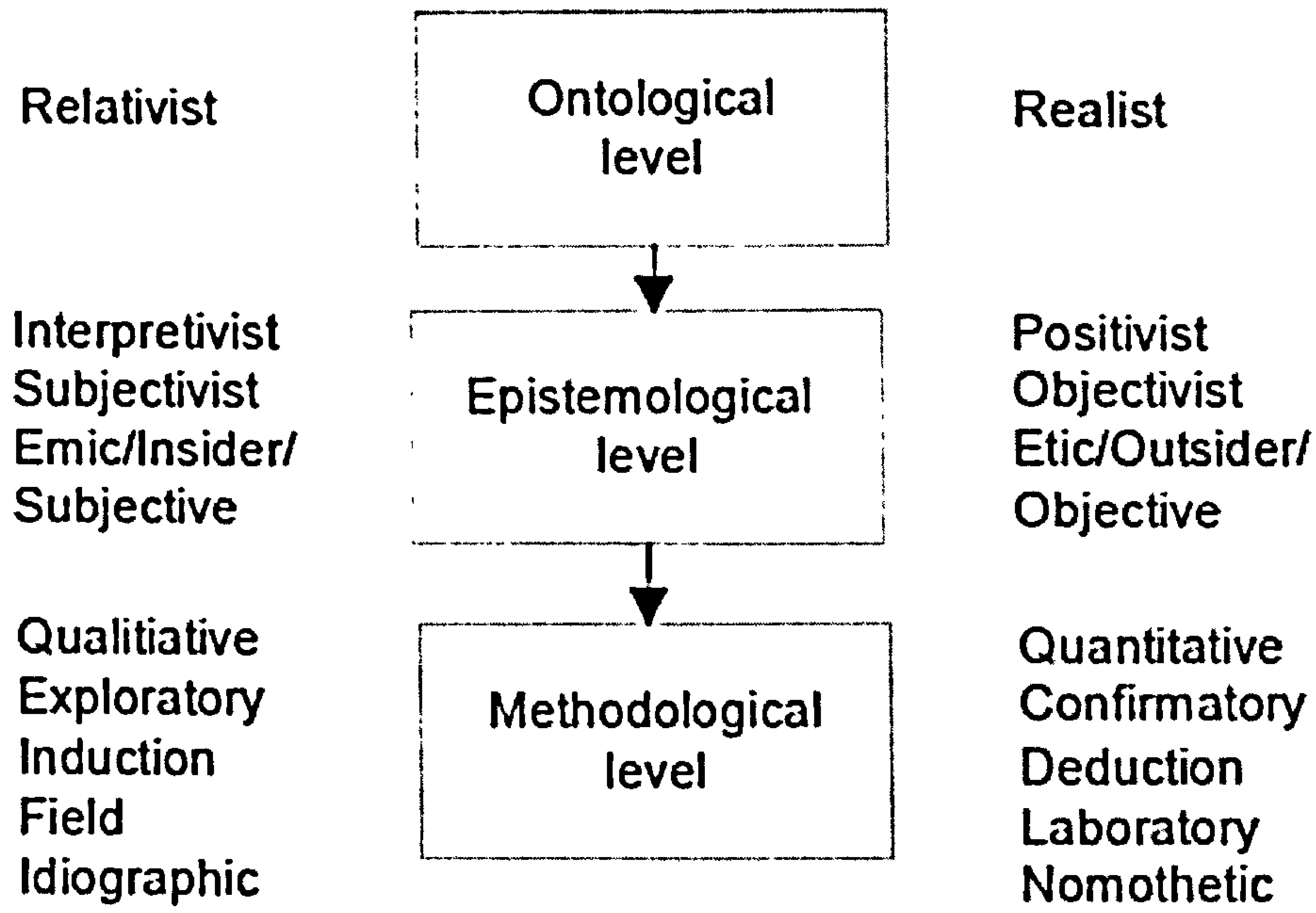


Figure 4. 2 Dimensional hierarchy and major related dichotomies in IS research. (Khazanchi and Munkvold, 2003)

Information System research based on different assumptions at each dimension can be categorised into different types. Khazanchi and Munkvold (2003) classified the Information System research paradigms into positivist, interpretive and critical research, and discussed their assumptions related to each dimension. The comparison of the three IS research paradigms is illustrated in Table 4.2.

- **Positivist Research.** The ontologically assumptions of the positivist position include the "naive" or "minimal realism" and a belief that only observable things are real and worthy of study. The epistemological assumptions of the positivist position contain the verification of hypothesis through rigorous empirical testing, the search for universal laws or principles and tight coupling among explanation, prediction and control.

- **Critical Research.** Critical research from a historical realist perspective ontologically assumes that the world is not a universe of facts that exists independently of the observer, and adopts relativism as its ontological basis. The epistemological assumptions of critical research suggest that objective observation is impossible and that all knowledge is generated or justified in the context of the researcher's framework and assumptions.

- **Interpretive Research**. Interpretive research is similar in the epistemological assumptions that objective observation is not possible, but intepretivism includes the additional facet that human experience is a process of interpretation of meanings and actions. Another difference is the transformative nature of the first, implying a focus on changing the status, whereas interpretivist research can be regarded as more 'neutral' and descriptive in this sense.

	Positivist[1]	Interpretivist	Critical Research
Ontological Assumptions	"Naive Realism" in which an understandable reality is assumed to exist, driven by immutable natural laws. True nature of reality can only be obtained by testing theories about actual objects, processes or structures in the real world.	Relativist; the social world is produced and reinforced by humans through their action and interaction	Historical realist; social reality is historically constituted; human beings, organizations, and societies are not confined to existing in a particular state
Epistemological Assumptions	• Verification of hypothesis through rigorous empirical testing • Search for universal laws or principles • Tight coupling among explanation, prediction and control	• Understanding of the social world from the participants' perspective, through interpretation of their meanings and actions • Researchers' prior assumptions, beliefs, values, and interests always intervene to shape their investigations	• Knowledge is grounded in social and historical practices • Knowledge is generated and justified by a critical evaluation of social systems in the context of researchers' theoretical framework adopted to conduct research
Relationship between Theory and Practice	• It is possible to discover universal laws that govern the external world	• Generative mechanisms identified for phenomena in the social sciences should be viewed as 'tendencies', which are valuable in explanations of past data but not wholly predictive for future situations	• Generalizations point to regularities of process rather than cross-sectional differences • Generalization in critical research focuses on the "totality" of relationships • There can be no theory-independent collection and interpretation of evidence to conclusively prove or disprove a theory
Role of the Researcher	Objective, impartial observer, passive, value-neutral	Interactive; the researcher interacts with the human subjects of the enquiry, changing the perceptions of both parties	Transformative; initiating change in social relations and practices, helping to eliminate the bases of alienation and domination

Table 4. 2 The comparative overview of the key rhetoric of major IS research paradigms. (Khazanchi and Munkvold, 2003)

4.3.3 RESEARCH PARADIGM FOR THE THESIS

This thesis like many others in Information System research holds to the realist perspective at the ontological level and adopts the assumption that an objective physical and social world exists independently of humans and whose nature can be apprehended, characterised, and measured. In this thesis, construction information management and mobile computing are understood to be objective and to have form and a reality beyond the actions of construction personnel, and then are capable of being represented via a number of research constructs and measures. The aim of this thesis is to 'discover' or 'explore' the form and reality of how to use mobile computing to manage on-site construction information by designing precise research instruments that will detect these dimensions of reality. The thesis assumes that there is a one-to-one correspondence between the constructs of the framework of using mobile computing in construction site information management and the 'objects' or 'features' of the form or reality for the research interest.

However, the position of this thesis is not at the extreme place of the dichotomies in the research paradigm. It takes the form of critical realism that refers to any position that maintains that there exists an objectively knowable, mind-independent reality, whilst acknowledging the roles of perception and cognition (Archer et al., 1998). In short, all knowledge is local, provisional and context-dependent.

This thesis, in common with much information system research, reflects a positivistic orientation at the epistemological dimension. It adopts the assumptions that the world conforms to fixed laws of causation and the empirical world is largely characterised by knowable, constant relationships. Its belief is that any knowledge claim or scientific explanation can be arrived at by means of sensory experience. This research assumes that there are fixed relationships within the phenomena referring to the implementation of mobile computing in construction site information management. It also assumes that the valid knowledge in terms of the relationships between mobile computing and construction information management can be obtained by appropriate research methodologies.

On the other hand, there is a trend in the information system research field that has incorporated a number of disciplines, such as computer science, management and organisational studies, social science, and philosophy (Orlikowski and Baroudi, 1991). Orlikowski and Baroudi (1991) argued that the adoption of a positivistic research approach in the information system field implies focusing on only certain aspects of the phenomena and limiting what and how researchers have studied information systems in organisations. This research realised that reality is socially constructed and open to various interpretations by participants, and intended to develop an understanding of mobile computing in construction information management from various perspectives.

Methodological assumptions indicate the selection of appropriate research methods to gather valid empirical data. As this research mainly holds the positivist perspective, it chooses the large-scale sample survey as the primary research method, since a sample survey allows researchers to control data collection and analysis through manipulation of research design parameters and statistical procedures.

However, as discussed at the epistemological dimension that the adoption of a positivistic research method only focuses on certain aspects of the research phenomena, the selection of research methods should focus on the nature of the phenomenon under investigation. Therefore, the research adopts a multi-methodology approach according to the objectives of the research, and this multi-methodology approach will be discussed in the following sections.

4.4 METHODOLOGICAL CONSIDERATIONS

Research methodology refers to the principles and procedures of logical thought processes which are applied to a scientific investigation, and research method concerns the techniques which are available and those which are actually employed in a research project (Fellows and Liu, 1997). This section consists of the argument of research methodology for the research area of information technology in construction, the discussion of multi-methodology approaches, and the introduction of common research methods.

4.4.1 RESEARCH METHODOLOGY FOR INFORMATION TECHNOLOGY IN CONSTRUCTION

After the classification of ITC (Information Technology in Construction) research into three research fields, Björk (1999) pointed out the methodological problems existing in this area. One problem is the application of standard scientific methods to the ITC research area, since ITC research is usually concerned with the development of tools which change reality rather than with studying reality without influencing it. This problem leads to the difficulty of choosing standard scientific research methods and design appropriate research methodology that are suitable for the phenomena under investigation. Another problem concerns the scale of the systems and the tests needed to prove some hypotheses that have re-engineering effects of particular categories of IT tools.

Björk (1999) further indicated that it would be relatively straight-forward to apply standard scientific techniques in the research areas of expert systems and IT-strategy research. For example, expert system research can be set up into rigorous experiments in order to compare the performance of expert systems to the performance of human experts. For IT-strategy research, standard sampling and interviewing techniques, which are used in many social sciences, can be applied straightforwardly in this field. However, he argued that the full-scale testing of product model research is costly and difficult because of the highly complex nature that involves data exchanges between several different types of IT applications, and he then listed a number of methodological weaknesses from a scientific viewpoint in product model research.

Unlike Björk who discussed methodological issues according to three different fields, Turk (1999) described the general application of scientific methods in construction IT research as follows:

- The "technology push" viewpoint that evaluates what some information technologies can offer and finds a problem it can solve, or select the technologies, which seemed appropriate for a problem in the construction industry.
- The hypothesis is normally, "this is a good approach, it can be used…".
- Model the construction industry's products and processes for the selected technology.
- Write the software to prove the hypothesis with a prototype.

Then, Turk (1999) pointed out the current status of applying scientific methods in construction IT results in three major faults:

- The hypothesis is not well defined, measurable and verifiable. Because natural sciences are not changed or influenced by observation and most construction IT constructs are 'constructs of the constructs made by actors' and are therefore influenced by the observer, the hypothesis of construction IT research is vague and cannot be proved by methods used in natural sciences.
- The value of research prototypes is very doubtful. The prototypes prove little until implemented by CAD companies and actually used industrially. There is a tendency of growing complexity in model invention rather than applying practices.
- The interpretation of the models and prototypes is done by intelligent and flexible humans. The approach of cross-examination and refutation is rarely used.

Other problems relating to the research of modelling processes in construction IT were identified by Crook et al. (1996), who discovered the following problems:

- the neglect of the informal communication in organisational processes that leads to the rationalist approach to override the actor's point of view;
- the creation of paradoxes through abstraction; and
- the failure to realise the difficulties involved in identifying the Functional Primitive Task.

In order to 'fit the obdurate character of the empirical world under study', Crook et al. (1996) provided an alternative research paradigm that has the belief that what is essential about business processes is the ideas held by those who participate in them. This research paradigm suggests that 'people act on the basis of what things mean to them in particular contexts'; that 'the meaning of things arises out of the social interaction that occurs in such contexts'; and that 'meanings are handled in, and modified through, an interpretive process used by the person in dealing with the things s/he encounters'.

4.4.2 THE MULTI-METHODOLOGY APPROACH

Multi-methodology refers to the utilisation of more than one methodology possibly from different paradigms within a single intervention and there are a number of ways in which such combinations can occur, such as methodological isolationism, methodology enhancement, methodology selection, methodology combination, and multi-methodology (Mingers and Brockesby, 1997). In this definition, the term 'intervention' covers a variety of situations from the classic consultancy case of external agents entering an unknown situation and leaving at the completion of the project; through multiple projects with the same organisation over time; to someone using methodology in their own workplace.

Mingers and Brocklesby (1997) then summarised three major types of combinations for multi-methodology. First, a methodology selection is the selection of whole methodologies as appropriate to a particular situation, which indicates generally only one methodology will be used in a particular intervention. This is based on the idea that methodologies from different paradigms make particular assumptions about the contexts within which they will be used, so that a methodology is most appropriate for a context matching its assumptions. Second, different whole methodologies may be used within the same intervention to deal with different issues or to provide different viewpoints. Third, the most complex form of multi-methodology is where methodologies are split or partitioned into components and these are combined together to construct a multi-methodology suitable for a particular problematic situation. The parts may come from methodologies in different paradigms.

After the understanding of what is meant by multi-methodology, it is therefore necessary to know the arguments that support multi-methodology. Mingers (2002) provided three major arguments in favour of multi-methodology:

- **The multi-dimensional world.** The real-world problems are highly complex and multi-dimensional. Each type of paradigm only focuses attention on a single aspect of the situation and so multi-methodology is necessary to deal effectively with the full richness of the real world. The adoption of a single approach is like viewing the world through a particular instrument and only reveals certain aspects of the world but is completely blind to others. This argument is a strong one in support of multi-methodology.
- **Intervention as a process.** The second argument is that intervention is not a single, discrete event but is a process that goes through several phases, each of which has different task requirements. There are four phases of a project that have been identified: appreciation, analysis, assessment, and action. It is clear that a wide variety of methods is not always suitable at all of these phases. Therefore, a specific methodology tends to be more suitable in relation to some phases rather than others, and the combination of a range of approaches may obtain a better result.
- **Triangulation of Results.** The third argument is that combining different methods can often provide a 'triangulation' on the situation and generate new insights into the results by validating each other. One approach is to use different methods to carry out a similar function, and the other is to take a particular method and then use it in an unusual way.

In order to answer the question of "*when should quantitative and qualitative research methods be combined?*", Falconer and Mackay (1999) first divided researchers into four main groups: positivist researcher, within-paradigm accommodators, cross-paradigm accommodators, and non-positivist research. The second group of within-paradigm accommodators refers to researchers who combine quantitative and qualitative methods from a positivist perspective, and the third one indicates that researchers attempt to combine positivist and non-positivist methods. The question of "*when should quantitative and qualitative research methods be combined?*" refers to the second group of researchers who frequently combine qualitative and quantitative methods within positivist research designs based on the nature of their research.

Another key question about multi-methodology is "*how can various research methods be combined?*" Mingers and Brocklesby (1997) provided a framework that links together different methodologies or parts of methodologies in a systematic way. They used a grid to combine two features of interventions, which are their multi-dimensionality and the different types of activity that need to be undertaken, and mapped the characteristics of different methodologies into this grid in order to link them together.

4.4.3 RESEARCH METHODS

Before discussing research methods, it is necessary to distinguish the terms of 'methodology' and 'method'. Mingers (2002) clarified three usages of the term 'methodology': i) 'methodology' means the study of methods; ii) 'methodology' normally refers to a particular project; and iii) particular combinations of methods come to be called 'a methodology'. Therefore, a 'methodology' is the structured set of guidelines or activities to assist people in undertaking research or intervention, and a 'method' or 'technique' is a specific activity that has a clear and well-defined purpose within the context of a methodology.

Research methods can be broadly categorised as quantitative and qualitative (Fellows and Liu, 1997):

- **Quantitative methods.** Quantitative methods use scientific techniques to obtain quantified data and then analyses the data to produce quantified results that are evaluated to test the hypotheses yielded from theories and findings from literature. Quantitative methods include structured surveys (interviews and questionnaires), experiments, and desk-based research of secondary data.
- **Qualitative methods.** Qualitative methods investigate the beliefs, understandings, opinions, views of people, and seek to gain insights and to understand people's perceptions of the 'world' so that theories will emerge. Qualitative methods contain unstructured surveys (interviews and questionnaires), case studies, and action research.

Although research methods can be generally divided into quantitative and qualitative, Fellows and Liu (1997) argued that research methods are not mutually exclusive and the different research methods focus on collection of data rather than examination of theory and literature. The major research methods or styles are discussed in more depth in the following sections.

Literature Review

A literature review is fundamental to all research methods. Fellows and Liu (1997) defined that literature concerns findings from research which have not attained the status of theory and often presents findings from research into particular applications of theory. Literature should be considered in the context of theory, methodologies, data, analytic techniques, sampling, and findings, so that objective evaluation takes place. The review of literature provides and demonstrates appreciation and an understanding of the state of knowledge of the topic and its context. It should provide the summary of the 'state of the art' for the extent of knowledge and issues regarding the topic, which inform the rationale for the ongoing research.

In summary, the purposes of the literature review include:

- the definition of topic and problem;
- the demonstration of understanding for state of relevant knowledge;
- the summary of the 'state of the art' of relevant knowledge;
- the highlight of methodologies that have previously been used;
- the gaps of previous research; and
- the potential area for further research.

Action Research

Action research involves active participation by the researcher in the process under study for identifying, promoting and evaluating problems and potential solutions (Bell, 1993). Action research is not only a research that describes how humans and organisations behave in the outside world but also a change mechanism that helps humans and organisations reflect on and change their own systems (Reason and

Bradbury, 2001). "Inasmuch as" that is designed to suggest and test solutions to particular problems is one type of action research and falls within the applied research category. The process of detecting the problems and alternative courses of action may lie within the category of basic research. The consideration of quantitative as opposed to qualitative categories may be equally usefully.

Ethnographic Research

Ethnographic research requires less active 'intrusion' by the researcher who becomes part of the group under study and observes subjects' behaviours and statements to obtain insights into what, how, and why their patterns of behaviour occur (Fellows and Liu, 1997). The determination of cultural factors including value structures and beliefs may result; however, the degree of influence caused by the presence of the researcher will be very difficult to determine. Typical ethnographic research employs three kinds of data collection: interview, observation, and document. This in turn produces three kinds of data: quotations, descriptions, and excerpts of documents, which result in one product: narrative description. This narrative often includes charts, diagrams and additional artifacts that help to tell "the story" (Hammersley, 1990).

Survey

Survey research is the method of collecting information by asking a set of pre-formulated questions in a pre-determined sequence in a structured questionnaire to a sample of individuals drawn so as to be representative of a defined population (Hutton, 1990). Surveys operate on the basis of statistical sampling where the samples are surveyed through questionnaire or interview. For a given sample size of responses required, researchers should consider the response rate and number of responses obtained. Following determination of the sample size required, appropriate procedures must be followed to assist in securing the matching of responses to the sample selected. Samples are then classified into categories by size or measured degrees of some important and continuous attributes (Fellows and Liu, 1997).

Case Study

The definition of case study has been viewed in two parts. First, Yin (2003) defined 'the scope of a case study: a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.' Because phenomenon and context are not always distinguishable in real life situations, the second part of the definition includes technical features, such as data collection and data analysis strategies. Yin (2003) further stated that 'the case study inquiry copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from the prior development of theoretical propositions to guide data collection and analysis.' Case study also has a major role to play in increasing industry uptake of construction IT solutions (Bloomfield, 1998). It can provide the industry with examples of how IT solutions have been successfully adopted and details of the context including the costs and benefits involved.

Modelling

Modelling is the process of constructing a model that represents a designed or actual object, process or system, and a reality. All models contain parameters (variables) together with their interrelationships. Fellows and Liu (1997) introduced the following classification of models:

- **Material models.** Transformations of original physical objects.
- **Formal models.** Logical, symbolic assertions of situations, the assertions representing the structural properties of the original, factual system.
- **Open-box models.** Predictive models for which, given all inputs, the outputs may be determined.
- **Closed-box models.** Investigative models, designed to develop an understanding of the actual system's output under different input conditions.
- **Iconic.** Visual or pictorial representation of certain aspects of a real system, such as computer screen icons to denote programmes; detail drawings of parts of a building.
- **Analogue.** Employs one set of properties to represent some other set of properties which the system possesses.
- **Symbolic.** Requires logical or mathematical operations.
- **Replications.** Display significant physical similarity to the reality.
- **Formalisations.** Symbolic models in which more of the physical characteristics of the reality are reproduced in the model; symbols are manipulated by techniques of a well founded discipline such as mathematics.
- **Simulations.** A formalisation model but without entire manipulation of the model by the discipline's techniques in order to yield an analytic solution or a numerical value.

There are a number of stages to set up a model. Figure 4.3 shows the modelling process that consists of the following stages (Fellows and Liu, 1997):

- **Objectives for the model.** The objectives of the model indicate the purposes of the model and the questions that the model intends to answer. The phenomena for which the model is to be constructed should be clearly stated in order to explain the perspective to the modelling.
- **Analyse reality.** The analyse stage comprises organised and analytic procedures to determine the operation of the reality and the location and permeability of the boundary of the system to be modelled.
- **Synthesise.** In the synthesise stage, diagrams will be used to reflect the reality with the identification of variables and their relationships. This stage will yield one model or an array of alternative models.
- **Verification.** The verification of a model involves the determination of whether the structure of the model is correct, which is achieved by testing the model and by examining the outputs resulting from the model under a given set of inputs. The model is verified if the outputs are appropriate.
- **Validation.** The validation stage compares the model's output resulting from known inputs to realisations of the reality. If a number of models have been suitably verified, it is usual for validation to be used to select the most appropriate models. Verification may suggest a model which is 'best' on the basis of theoretical 'fitting' from criteria based on analysis of the model. The selection of model will depend on the objective of the modelling exercise, its use and by whom it will be used.
- **Use model.** Once the structure of the model has been established and its performance is verified and validated to be suitable for the objectives, the final stage is to use the model for analysis, predictions and technique of 'inference' for making predictions, which are based on the purposes of the model.

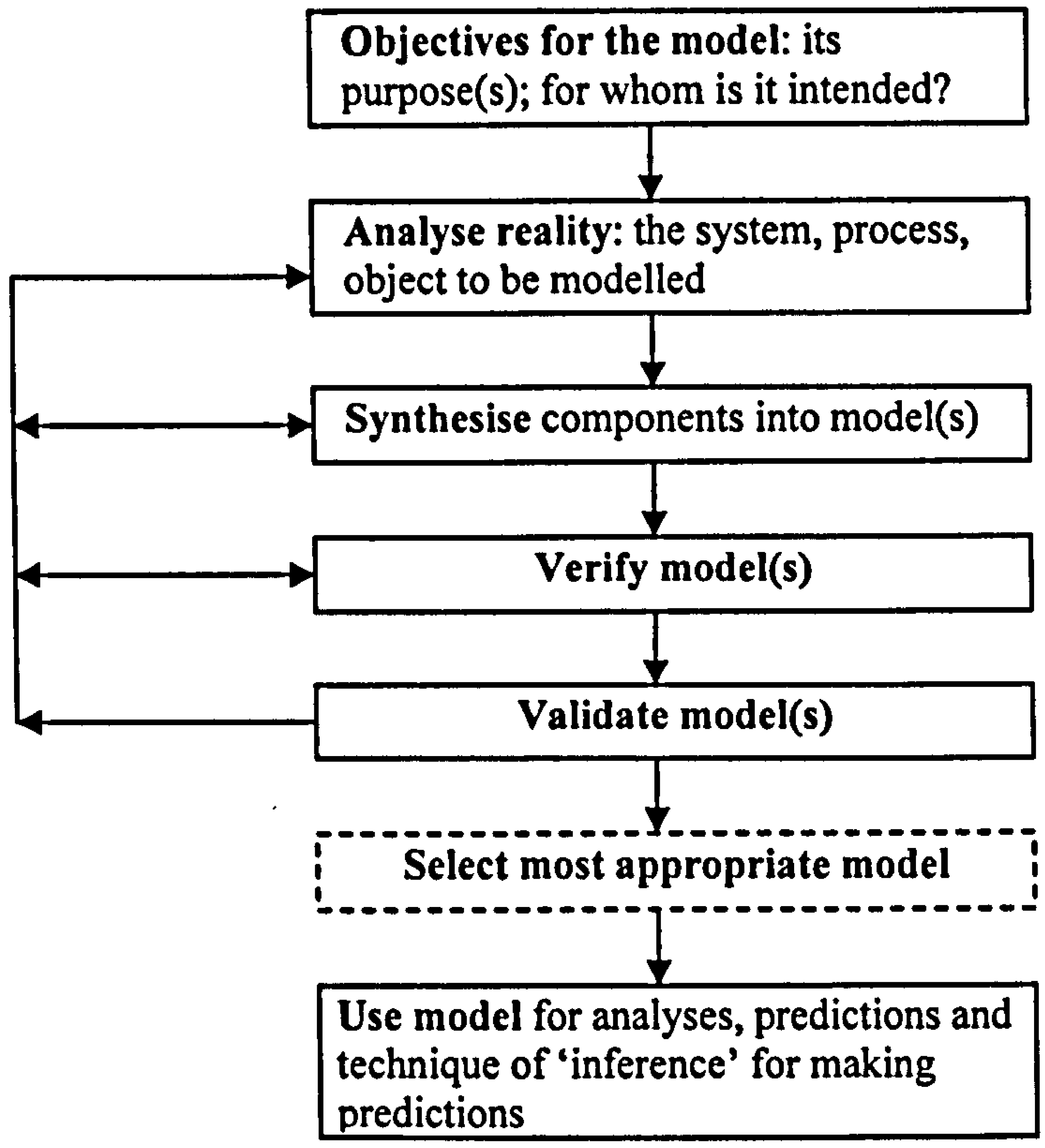


Figure 4. 3 The modelling process (Fellows and Liu, 1997)

4.5 RESEARCH DESIGN

In order to achieve the research objectives and answer research questions, the research strategy should be appropriately designed according to the phenomenon under investigation. This section introduces the selection of research methods, discusses the design of research strategy, and explores the advantages and disadvantages of selected research methods.

4.5.1 RESEARCH METHOD SELECTION

Although there are many arguments about the multi-methodology approach and qualitative and quantitative research methods, which have been discussed in previous sections, Falconer and Mackay (1999) stated that researchers should focus on the nature of the phenomenon to be investigated rather than the research methodology. Wing et al. (1998) supported this view and further indicated that all established research methods in both the quantitative and qualitative types have a contribution to make at various points in the research process depending upon the existing body of knowledge in the research area, the objectives and perspectives of the research and the quality of available data. However, Wing et al. (1998) argued that the key thing for researchers is the explicit description of the approach to the selection and framing of research problems, the methods used, the actual processes employed to establish findings and all assumptions.

This research project adopted a multi-method research approach that results in the selection of a range of research methods to be used during the research process. In determining which research method is suitable for selection, Yin (2003) discussed three conditions for different research strategies, see Figure 4.4.

- **Form of research question.** The basic forms of research questions can be classified into the following categories: "who", "what", "where", "how", and "why". Research questions like "what", "who" or "where" are normally exploratory and actually a form of a "how many" or "how much" line of inquiry. These types of questions are suitable for survey strategies or the analysis of archival records. In contrast, "how" and "why" questions are more explanatory and are appropriate to the use of case studies, histories, and experiments. The selection of research strategies based on the types of research questions has led to the defining of the research questions becoming the most important step to be taken in a research study.
- **Extent of control over behavioural events.** The experiment is the only research strategy that can conduct research requiring the control of behavioural events. When an investigator needs to manipulate behaviour directly, precisely, and systematically,

the experiment can be done in a laboratory setting, in which this experiment may focus on one or two isolated variables, or it can be done in a field setting, where the 'social experiment' covers research in which investigators 'treat' whole groups of people in different ways.

- **Degree of focus on contemporary as opposed to historical events.** Historical research deals with the past, which means when no relevant persons are alive to report what occurred, and when a researcher must rely on primary documents, secondary documents, and cultural and physical artefacts as the main sources of evidence. The case study is suitable for investigating contemporary research when the relevant behaviours cannot be manipulated. Although the case study relies on many of the same techniques in comparison with historical research, the case study has two additional sources of evidence: direct observation of the events being studied and interviews with the people involved in the events. The unique advantage of a case study is its ability to deal with a full range of evidence including documents, artefacts, interviews, and observations.

Strategy	Form of Research Question	Requires control of Behavioural Events?	Focuses on Contemporary Events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case study	How, why?	No	Yes

Figure 4. 4 Relevant Situations for Different Research Strategies (Yin, 2003)

Since the available resources for carrying out the research project are finite and restricted, Fellows and Liu (1997) stated that the choice of a research method is affected by considerations of the scope and depth required. The scope of a research method is between a broad but shallow study at one extreme and a narrow and deep study at the other, or an intermediate position, as shown in Figure 4.5. In this figure, a questionnaire as a data collection method has the wide breadth of study but the depth of study is very shallow. In contrast, a case study has great depth of study with very narrow breadth. Additionally, the interview has an intermediate position in terms of breadth and depth compared with questionnaires and case studies.

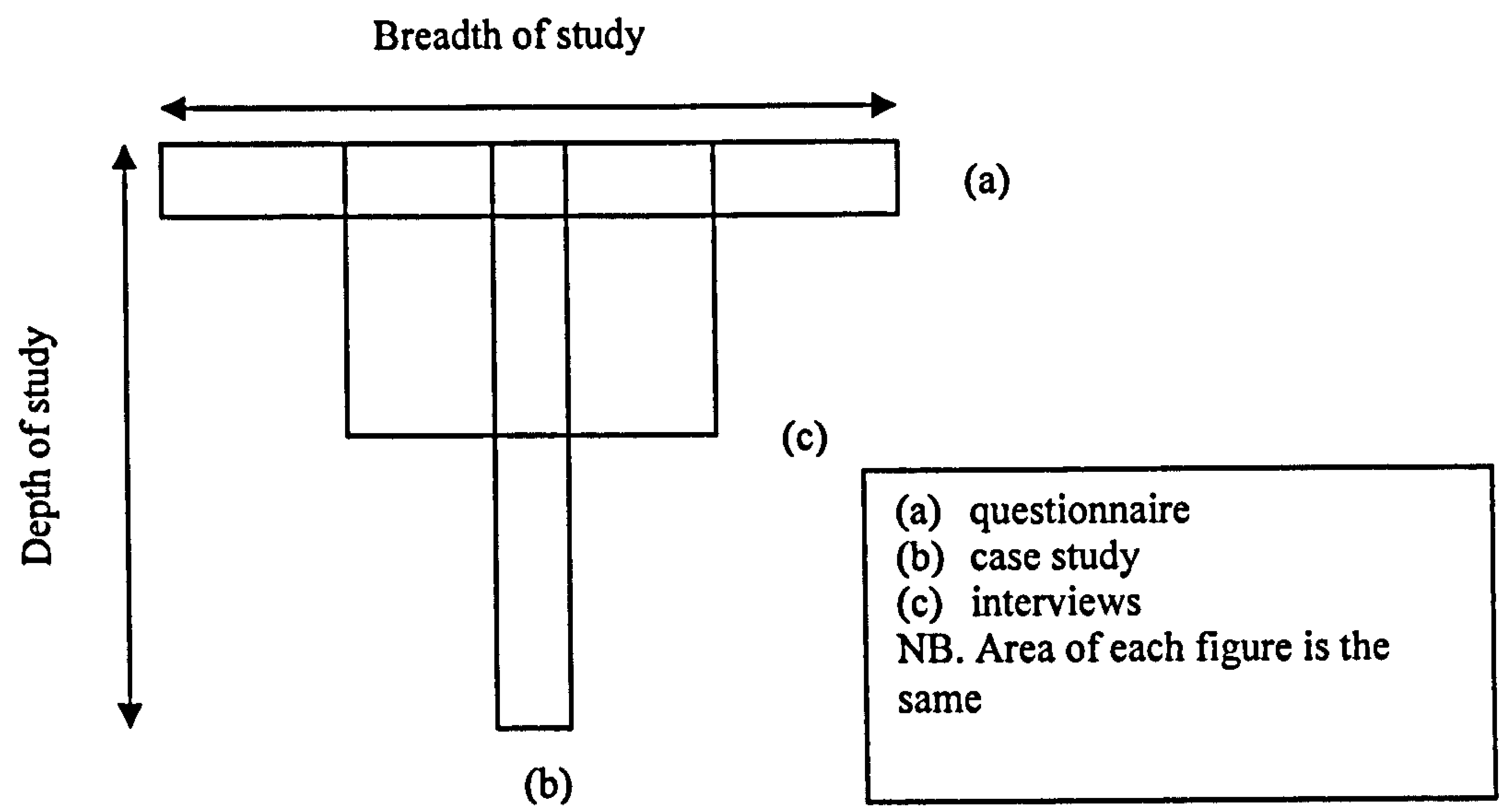


Figure 4. 5 Breadth v. depth in 'question-based' studies (Fellows and Liu, 1997)

4.5.2 RESEARCH METHODOLOGY AND SELECTED METHODS

As discussed in previous sections, the design of methodology and selection of research methods should consider the aims and objectives of the research and the research questions. Research questions arising from this research project's objectives include:

- What is meant by construction information management?
- How do construction personnel manage construction information on construction sites?
- What is the existing mechanism for information retrieval and transfer on construction sites?
- What are the current developments and practices of mobile computing in the construction industry?
- How can mobile computing be used on construction sites by construction personnel to manage on-site information?
- How can the developed framework be used in real construction situations?

In order to explore the above questions, Figure 4.6 illustrates the research strategy that consists of four steps employed in this research project and the research method used for each step.

Research Step	Research Objective	Research Question	Research Method
Step 1	To investigate the concept of construction information management.	What is meant by construction information management?	Literature Review
		How do construction personnel manage information on construction sites?	Case Study
		What is the existing mechanism of information retrieval and transfer on construction sites?	Survey
Step 2	To investigate the state of art of mobile computing technologies and their practices in the construction industry.	What are the current developments and practices of mobile computing in the construction industry?	Literature Review
Step 3	To develop a framework to explore the use of mobile computing in construction site information management.	How can mobile computing be used on construction sites by construction personnel to manage on-site information?	Modelling
Step 4	To demonstrate the validity of the framework through an illustrative example.	How can the developed framework be used in real construction situations?	Case Study

Figure 4. 6 Research strategy and selected research methods

4.5.3 ARGUMENTS OF RESEARCH METHODOLOGY

It is important for researchers to evaluate the chosen research methods in order to deal with the potential criticisms of each method at an early stage; therefore, researchers should have a good understanding of the advantages and limitations of a particular research method before designing the research methodology. The understanding of the advantages and limitations for different research methods can help researchers to improve the design or data collection process as a response to criticisms or concerns about the appropriate use of a particular method.

There are two major research methods whose advantages and limitations need to be considered in this research project: case study and survey. For case study, Blaxter et al. (2001) summarised the following advantages and disadvantages:

Advantages:

- Case study data drawn from people's experiences and practices are seen to be strong in reality.
- Case studies allow for generalisations from a specific instance to a more general issue.
- Case studies that explore alternative meanings and interpretations allow researchers to show the complexity of social life.
- Case studies can provide a data source from which further analysis can be made.
- Because case studies build on actual practices and experiences, they can be linked to action and their insights contribute to changing practice.
- Because the data contained in case studies are close to people's experiences, they can be more persuasive and more accessible.

Disadvantages:

- The complexity of a case can make analysis difficult. This is particularly important because of the holistic nature of case study, which means that the researcher is often very aware of the connections between various events, variables and outcomes.
- While the contextualisation of aspects of the case strengthen this form of research, it is difficult to know where 'context' begins and ends.

Although case study is a distinctive form of empirical inquiry, there are a number of traditional prejudices and concerns against the case study strategy. Yin (2003) discussed the following three concerns about case studies:

- The greatest concern is the lack of rigor of case study. The case study investigator usually has not followed systematic procedures, or has allowed equivocal evidence or biased views to influence the direction of the findings and conclusions. The possibility of the lack of rigor is because people have confused case study teaching with case study research and because that bias also can enter into the conduct of experiments is often forgotten.
- The second concern about case studies is that they provide little basis for scientific generalisation. The approach that can be used is the multiple-case studies with a different concept of the appropriate research designs. Case studies are generalisable to theoretical propositions and not to populations or universes. The aim of case studies should be to expand and generalise theories (analytic generalisation) and not to enumerate frequencies (statistical generalisation).
- The consideration of case studies is that they take too long and result in massive, unreadable documents, which incorrectly confuses the case study method with a specific method of data collection. In contrast, case studies are a form of inquiry that does not depend solely on such data collection methods such as ethnographic or participant-observer data.

Survey as the primary research method in the research project should be fully understood in terms of its advantages, limitations, concerns, and restrictions, before the design and conduct of the research. For the survey method, Blaxter et al. (2001) summarised the following advantages and disadvantages:

Advantages

- Questions answered by an individual can be applied to the whole sample and answers from individual interviews can be added together to produce results.
- The research is based on interviews with a representative sample of respondents.
- The questions are designed to be unbiased.
- Surveys lend themselves to future replication.
- Large surveys can often be broken down.

Disadvantages

- The main focus of the research report is the data, in the form of tables, pie charts and statistics, which leads to the loss of linkage to wider theories and issues.
- The data provides snapshots of points in time rather than a focus on the underlying processes and changes.
- There are some issues of truthfulness and accuracy, because researchers are often not in a position to check first hand the understandings of the respondents to the questions asked.
- The survey relies on breadth rather than depth for its validity, which is a crucial issue for small-scale researchers.

After reviewing the previous discussions about survey research, Burton (2000) argued that criticisms of survey research can be classified into three main categories: philosophical, technical and political.

Firstly, the philosophically based criticisms focus on the following points:

- Surveys cannot establish causal links between variables.

- Surveys are incapable of getting at the meaningful aspects of social action.
- Surveys merely assess a particular aspect of some social phenomenon without placing it in a context in which actions occur.
- Surveys often assume that human action is determined by external forces and neglect the role of human action.
- Survey research is based on a rigid science model of hypothesis and significant testing which involves little imagination or creative thinking.
- Survey research is empirically based which contributes little of theoretical value.
- Some things are not measurable by surveys.

Secondly, the technical issues of criticisms mean the standardised questionnaire items often represent the least common denominator in assessing people's attitudes, orientations, circumstances, and experiences. Moreover, the coding procedures and question formats used in a survey serve to reduce the variety of individual responses to fairly clear-cut, firmly bounded categories necessary for variable analysis. Another criticism is the inflexibility of survey, which indicates its standard practices that should remain the same throughout the project, once the standard survey procedure has been constructed. Finally, survey research is too statistical, reduce interesting questions to incomprehensible numbers, and the methods used to analyse data can leave a lot to be desired.

The political criticisms of survey research include two major issues: that survey research is intrinsically manipulative by giving power and control to those who undertake such work which they can abuse, and that survey research does not produce knowledge about reality, but is an ideological reflection whose acceptance furthers particular interests.

4.6 THE RESEARCH UNDERTAKEN

According to the designed research methodology (Section 4.5.2), the research process conducted consists of the following stages: literature review, case study, survey, modelling and case study.

4.6.1 LITERATURE REVIEW

It is essential for all researchers to conduct a literature review to discover what relevant research has already been carried out and what progress may be achieved from the theoretical foundation. The literature reviewed for this research project dates back over several years and the literature materials included academic papers, books, industrial articles, industrial reports, technical specifications, and electronic resources. Because this research was cross-disciplinary, the literature review focused on two major areas: construction information management and mobile computing. Chapter 2 and Chapter 3 provide details of the review undertaken.

The outcomes of this stage were the conceptual framework that integrates technologies of mobile computing with the concept of information management, and the illustrative scenario that presents the possible way of using mobile computing in a particular construction situation.

4.6.2 CASE STUDIES

As shown in Figure 4.4, case studies are particularly suitable to answering 'how' and 'why' questions. In order to answer the question of how construction personnel manage information on construction sites, the second research step chose case study as the research method to investigate the general and practical situation of managing information on construction sites.

The case studies used a combination of personal observation and interviews to investigate the ways construction personnel manage information on construction sites. Objectives of the case studies were to understand the general circumstance for construction sites, to identify on-site construction personnel, to classify their information needs, and to investigate the current state of on-site IT support.

To achieve the proposed objectives, the case studies conducted included the following steps:

- **Identification of construction sites.** The first step was achieved through searching the Internet and local newspapers to find out who was undertaking construction projects in the local area. Three construction sites with varying project types were identified as appropriate cases. Projects included a theatre refurbishment project, a sports centre extension project, and a water supply project.
- **Document of project information.** Once a building project was targeted and the construction site was located, the site visit was then conducted. When arriving at a construction site, project information that needs to be documented includes project size, detailed address, project type, duration of construction, contractor name, construction company name, and number of site staff. This type of project

information was obtained from visiting site offices and having conversations with appropriate construction personnel. The first project was the theatre refurbishment project that was in the early stages of demolition and ground works. The second project actually consisted of two sub-projects including the extending project of a sports centre and the reform of a medical school. The project to extend the sports centre was a 4.5 million pounds project starting in July 2004 and ending in June 2005. The medical school project cost 9 million pounds and the construction period was from May 2004 to August 2005. The third construction project was the water supply project that was at the stage of concrete work.

- **Construction site observation.** Since one of the objectives of the case studies was to obtain a practical picture of the construction environment, it was helpful to walk around sites with an understanding of the safety guidelines on the construction site. The observation concentrated on the following aspects: the working conditions of onsite staff, their movement, activities of construction personnel, roles, and the differences between the workforce and managerial personnel.
- **Site staff interview.** The visit to site offices and the discussion of proposed interview issues with a site manager led to an agreement of who could be interviewed, where the interview could be conducted, and how long the interview would take. Managers or supervisors were asked for their help in identifying interviewees who had the characteristics required in the research project. Interviewees were asked to answer questions based on a prepared interview schedule. A number of factors, such as respondents' available time, interview accommodation, their training situation, the understanding of interview questions and their interest in this research topic, affected the interview process with respect to quality, depth, and usefulness of information obtained. However, since these were

small scope case studies and the requirements of obtained information were general and broad, data collected from the case studies were enough to answer the proposed research questions and to explore the potential difficulties and limitations of onsite studies in order to provide insights into how best to design the following survey study.

- **Data analysis.** Data obtained from interviews and observations were analysed through breaking the amounts of unstructured data into manageable chunks. This was done through a coding procedure in which chunks of text are labelled, and coded, and then stored by these codes.

Findings from the second stage of case studies are provided in Chapter 5.

4.6.3 THE SURVEY

In order to answer the question of what is the existing mechanism of information retrieval and transfer on construction sites, a web-based survey was conducted to investigate the information needs of particular users and the mechanism of retrieving and transferring information on construction sites. The first reason for selecting a survey as the research method was because the research question was an exploratory question that aimed to explore the reality of information retrieval and transfer rather than the investigation of people's beliefs, understandings, opinions, views and perception. The second reason was because the question should be answered from a broad study that can provide findings for the phenomenon under investigation instead of the specific and particular results from several individual cases.

The aim of the survey was to investigate the current mechanism of information retrieval and transfer on construction sites. In order to achieve this target, the survey looked at the following aspects: information needs of on-site construction personnel, the nature of information, sources and destinations of information transfer, mediums of information communication, approaches of construction work site information access and collection, and the users' perception of mobile computing.

The survey was conducted via the Internet, first as a pilot survey and then a final survey. The results of the pilot survey were excluded from the final analysis since it was corrected and improved for format and content problems in the structured questionnaires.

The survey was carried out as a web-based questionnaire rather than paper-based questionnaire because of the following considerations:

- There were many commercial products for conducting a survey. These commercial service providers included QuestionPro, Zoomerang and Quask, which can provide many services to fulfil different survey requirements, such as survey templates, spotlight reports, branching, randomisation, extract, piping, looping, cross-tabulations, and conjoint.
- A web-based survey can do a very sophisticated analysis, but the survey was simple to design and the data was automatically analysed and tabulated.
- The application of a web-based survey can reduce the time and finance budget that is spent on the survey process compared with paper-based questionnaires, such as a postal survey.

- A web-based survey can use hyperlinks or java scripts to provide respondents relevant examples, explanations or instructions.
- Display of response data can be simultaneous with completion of surveys. Often, data from Web-based surveys are available in real time in graphic and numerical format.
- Reminders and follow-up of non-respondents were relatively easy.

However, a web-based survey has its own limitations (Dillman, 2000). The limitations of a web-based survey had been considered before designing and conducting the survey. The limitations and the methods of avoiding these limitations are discussed as follows:

- A web-based survey only target respondents who have a computer with a connection to the Internet. Because this survey targeted construction managerial professionals and, according to the findings from the second stage of case studies, on-site managerial professionals usually had their own computer with a connection to the Internet, a web-based survey is suitable to create the sample frame.
- Even if connected, not all potential respondents are equally computer literate. This limitation was considered to be avoided via the design of the questionnaire with simple format, standardisation questions, relevant examples, explanations and instructions.
- Screen configurations may appear significantly different from one respondent to another, depending on the settings of individual computers. This limitation was avoided through the selection of a commercial Internet survey provider who could provide platform-independent services. The platform-independent survey service ensured that the web-based questionnaire was displayed at the same format regardless of respondents' computer configurations.

- Sampling of e-mail addresses is difficult. There are no directories. Sometimes there is more than one e-mail address per respondent. Addresses are not standardised. This survey selected samples from the New Civil Engineer (NEC) website that kept directories containing all types of construction companies, and maintained the list of respondents that ensured only one e-mail address for each respondent.
- The decision not to respond is likely to be made more quickly. In order to increase the return rate, reminder emails were sent out to all construction professionals in the later stages. The selected commercial Internet survey provider can record and update the progress of answering survey questions for each respondent based on their IP address; therefore, respondents who did not complete the questionnaire can restart the questionnaire at the point where they withdraw last time rather than the beginning of the questionnaire.

The pilot survey was conducted before the formal survey and pilot questionnaires were sent to construction professionals with the additional question that allowed respondents to give their advice and suggestions for the proposed questionnaire. Some respondent's advice was adopted in the formal survey such as reducing the length of the whole questionnaire, deleting the duplicated questions, designing the new formats of fewer questions, and reducing the number of open-text questions.

Participation in the survey was completely voluntary and respondents could withdraw from the survey at any point. The only incentive was the option to receive the findings of the survey. Emails containing the web link to this web-based survey were sent at the beginning of August 2005 and answers were collected between September 2005 and November 2005. Answers provided were kept confidential and data from this survey were used only for statistical purposes. All data from the survey were input into and analysed by statistical software SPSS. Findings of the survey are discussed in Chapter 5 in greater depth.

4.6.4 MODELLING

The fourth research step was to develop the framework that explores how mobile computing can be used on construction sites by construction personnel to manage on-site information. This framework firstly identified the key factors of mobile computing, construction personnel, construction information, and construction site; secondly it described the relationships and interactions among these factors. The intention was to use the framework to provide guidance in the effective deployment and selection of mobile computing strategies for on-site information management. Evidence that was used to build up this framework consists of findings from the literature review, case studies and the survey. According to the modelling process introduced in previous sections, the fourth research step contained several stages including the definition of objective, the analysis stage and the synthesis stage. The detailed description of the framework is in Chapter 6.

4.6.5 THE CASE STUDY

The validity of the developed framework needed to be demonstrated through an illustrative example. This final research step used case study as the research method to validate the developed framework in a real construction situation through the use of scenarios for specific construction operations.

There were three major steps for conducting the case study. The first step was to investigate the background information of the selected construction project. These kinds of information included the project name, project type, project budget, construction site location, duration of construction stage, contractor names, challenges it faced, and construction site layout. All of this information was obtained from a search of the project web site, visits to site offices and interviews with appropriate site personnel. The illustrative scenario based on a real construction environment and mobile computing technologies will be used to assist construction personnel to manage on-site information at a real site. Especially, characteristics of the construction site, such as site size, site environment, site layout and on-site construction processes, were identified according to the developed framework.

In the second step, a small scope survey was used to investigate the current situation of on-site information management. Questionnaires were distributed to construction personnel whose workplaces were based on the construction site offices and the construction work site. Of the ten distributed questionnaires, five responses were received which corresponds to a return rate of 50%. The questionnaire consisted of closed questions and open-ended questions aimed to investigate the roles of respondents, construction processes they were involved in, received and transferred information on the work site, information resources and destinations, and methods of information retrieval and transfer. At this step, features of potential users of mobile computing technologies and the characteristics of construction information transferred by mobile computing were identified based on the established framework.

The final step was to select a mobile computing strategy to manage on-site construction information for the illustrative project in accordance with a real construction environment. This step aimed to demonstrate the validity of the developed framework through the illustrative project. The objectives of on-site information management were set out, and the identification of mobile computing strategy followed; the appropriate mobile computing technologies were suggested to suit the characteristics of the illustrative project. The detailed introduction and discussion of the procedures for selecting mobile computing strategy is provided in Chapter 7.

4.7 SUMMARY

This chapter concentrated on the methodology adopted and used for the research project. It discussed the philosophical assumptions and the research paradigm within which the research has been conducted, and justified the use of a multi-methodology approach with the introduction of various research methods. It then provided details of the research design and the selection of different research methods. The potential criticisms of each selected method had been evaluated to provide a good understanding of what the advantages and limitations for a particular research method were in order to improve the design or data collection process. Finally, this chapter outlined the research process undertaken to satisfy the aims and objectives of the thesis.

CHAPTER 5

RESEARCH FINDINGS

5.1 INTRODUCTION

This chapter summarises findings from the empirical research including case studies and the survey. The research process was carried out according to the research methodology designed in Chapter 4.5, and the process undertaken was introduced in Chapter 4.6.

5.2 CASE STUDY FINDINGS

In order to answer the research question of how construction personnel manage information on construction sites, case studies were conducted to investigate roles on sites, the major information they need, and the current on-site IT support. Findings (Chen and Kamara, 2005b) from the case study are discussed in this section.

On-site respondents were first asked to identify their roles in each project. Roles identified in case studies included the project manager, quantity surveyor, general foreman, civil engineer, site engineer, quality administrator, office manager, demolition manager, ground work foreman, and labourer. The varieties of roles on construction sites are normally affected by project stages, types and sizes. For example, since the theatre refurbishment project was in the early stages of demolition and ground works, on-site construction personnel included not only the project manager, civil engineers and the general foreman, but also the demolition manager and ground work supervisors. The type of project is another concern that affects the roles on a construction site. If it is a new building project, construction processes would need a whole range of construction individuals to perform a variety of construction activities; however, regarding a project with limited construction activities, the necessary roles on sites would depend upon the requirements of the project. Project size is another factor that not only decides the number of construction personnel on site, but the tasks performed by specific roles. In a small size project, a middle-level manager may take responsibilities that could be taken by other specific managers in another larger size project. For example, the general foreman in the smaller size project of the theatre refurbishment had to take responsibility for site safety issues, which were explicitly taken into account by a safety manager in the larger size project of the water supply project.

The main information required by construction personnel to support their work is drawings. From interviews with civil engineers, they indicated that they had to spend lots of time analysing and checking construction drawings and it was necessary to carry them on work sites to assist their construction activities. Regarding the construction managerial personnel, such as project managers and general foremen, they need to be concerned about all aspects of the ongoing project and require multiple types of information, including drawings, specifications, documents, and site records, to assist them to make on-site decisions. On the other hand, managers or engineers from a specific department may need more detailed information associated with their work areas. For example, a quantity surveyor in a construction project requires information including tender and contracts documents, financial reports, budgets and cost plans, but it is not necessary for him to obtain information like structural drawings, material information, and equipment information, which should be retrieved by civil engineers. However, this does not mean that construction information required by construction personnel are separated and isolated; in fact, lots of information is received and shared by construction personnel from different disciplines. It is therefore necessary to build up an integrated information environment in which different users can share, access, and retrieve information resources to meet their information requirements and improve the efficiency of information communication.

From the visit to construction site offices, it is obvious that each middle-level manager in the project team has their own computer, normally a laptop in site offices. Computers in the site offices of a sports centre and medical school project can gain access to information resources in head office, design teams, and other departments through network connections. Construction information including drawings, documents, and contracts, are communicated via networks between the head office, design offices and site offices. However, none of these three projects apply mobile computing technologies to assist their information management tasks. A view about mobile computing from one of the project managers interviewed was that: "*The size of a PDA screen is too small for construction drawings. We prefer to use paper-based drawings that can be hung on the wall, so it is easy to discuss any construction details.*" The findings suggest that normal information technologies, including computer equipment, information management systems and wired networks, have extended to site offices, and have been accepted by most middle-level construction managers, but mobile computing is still a very new concept to construction personnel and the benefits of using mobile computing still needs to be demonstrated before it can be widely adopted.

5.3 FINDINGS FROM THE SURVEY

The aim of the conducted survey is to explore the existing mechanism of information retrieval and transfer on construction site. Findings from the survey coupled with the literature review and case study are used as evidence to develop the final framework (Chen and Kamara, 2006).

5.3.1 SAMPLE FRAME

The survey targeted managerial professionals who had sufficient working experience in the construction industry. The Web-site based database of New Civil Engineer (NEC) was used to make a representative selection of survey samples. The NEC database keeps directories containing all types of construction companies in the UK and these directories were updated regularly. The statistical selection method was the free random selection method that selects construction companies from UK's major construction contractors. A total of 160 firms from a total population of 2024 main contractors were selected and 220 invitational emails were sent to construction professionals who work in these firms. The selected professionals mainly consisted of senior executives, functional managers and site management personnel, regarding the identified roles on construction sites in early case studies. This resulted in a random selection of the statistical samples containing 220 construction professionals who had sound construction knowledge and who had experience working on construction sites. Of the

38 responses received, which corresponded to a return rate of 17%, 29 responses were complete and deemed suitable for the analysis.

The return rates for mail surveys in the construction industry are often around 10%, for example: 7% for the general survey in New Zealand (Doherty, 1997), 10% in Denmark and 16% in Sweden (Howard et al., 1998), and 9% in Saudi Arabia (O'Brien and Al-Biqami, 1999). For the web-based survey (Chan and Leung, 2003), the return rate was 16%. Findings presented here are based on an overall 17% return rate. In general, a mail survey cannot be considered statistically significant under a 50% return rate (Erdos, 1983). Even though a low-response rate was obtained, findings of the survey still present useful information about the respondents and show tendencies within the industry.

In order to increase the return rate of this survey, reminder emails were also sent out to all construction professionals in the early stages. Because the service provider of the web-based survey can list information about respondents who started the survey but did not complete it and those who only reviewed the survey but did not start it, email reminders were then sent to these particular respondents to ask them to continue to complete all survey questions. When clicking the web link of the survey, respondents who did not finish the survey would automatically start the survey from the point where they withdrew last time. This was because the web-based survey automatically recorded such information of respondents as their IP address, email address, start time, finish time, and their progress in completing the survey.

5.3.2 RESPONDENT DETAILS

5.3.2.1 Respondent Profiles

All of the 29 respondents surveyed come from main construction contractors. Of the respondents, 14% are senior executives, 45% are functional management staff, and 41% are on-site management staff and engineers. The functional management staff consists of quantity surveyors (17%), quality managers (14%) and proposals managers (14%). Figure 5.1 shows the proportion of all the respondents surveyed in terms of job titles.

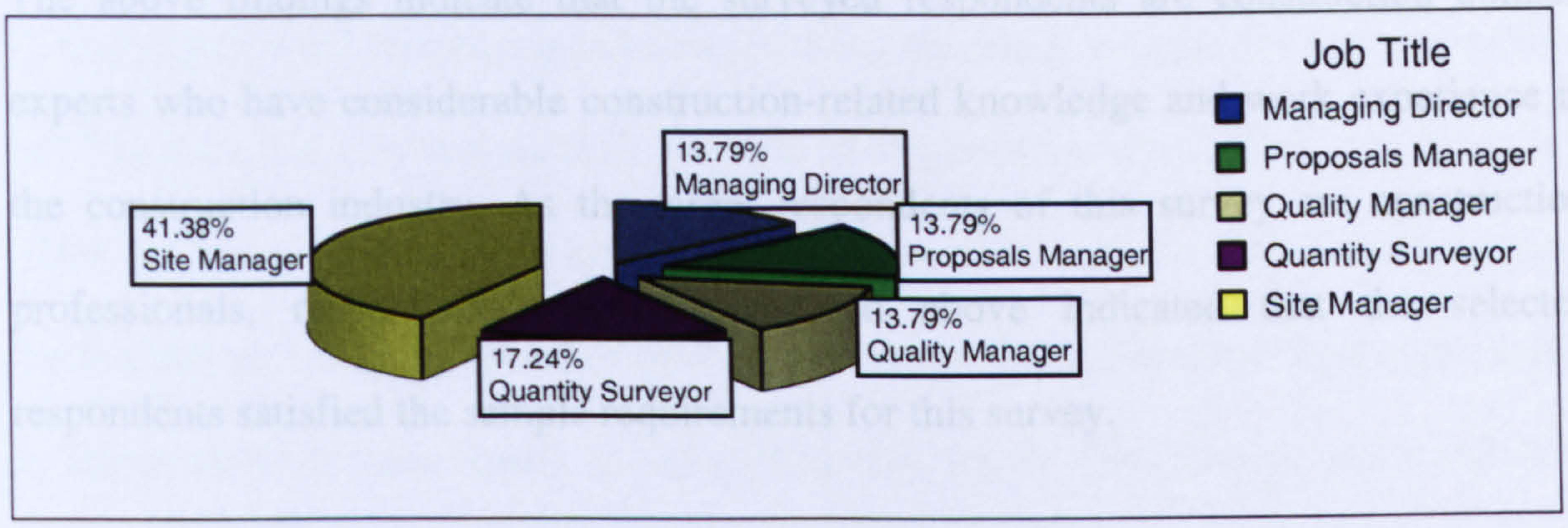


Figure 5. 1 Proportions of respondents surveyed in terms of job title

Another important characteristic of respondents is their working experiences. Figure 5.2 shows that the work experience of respondents surveyed vary from less than 1 year to more than 20 years. Almost 55% of the respondents have worked in the construction industry for more than 20 years. The minimum time of working experience of respondents is 11 months and the maximum is 49 years.

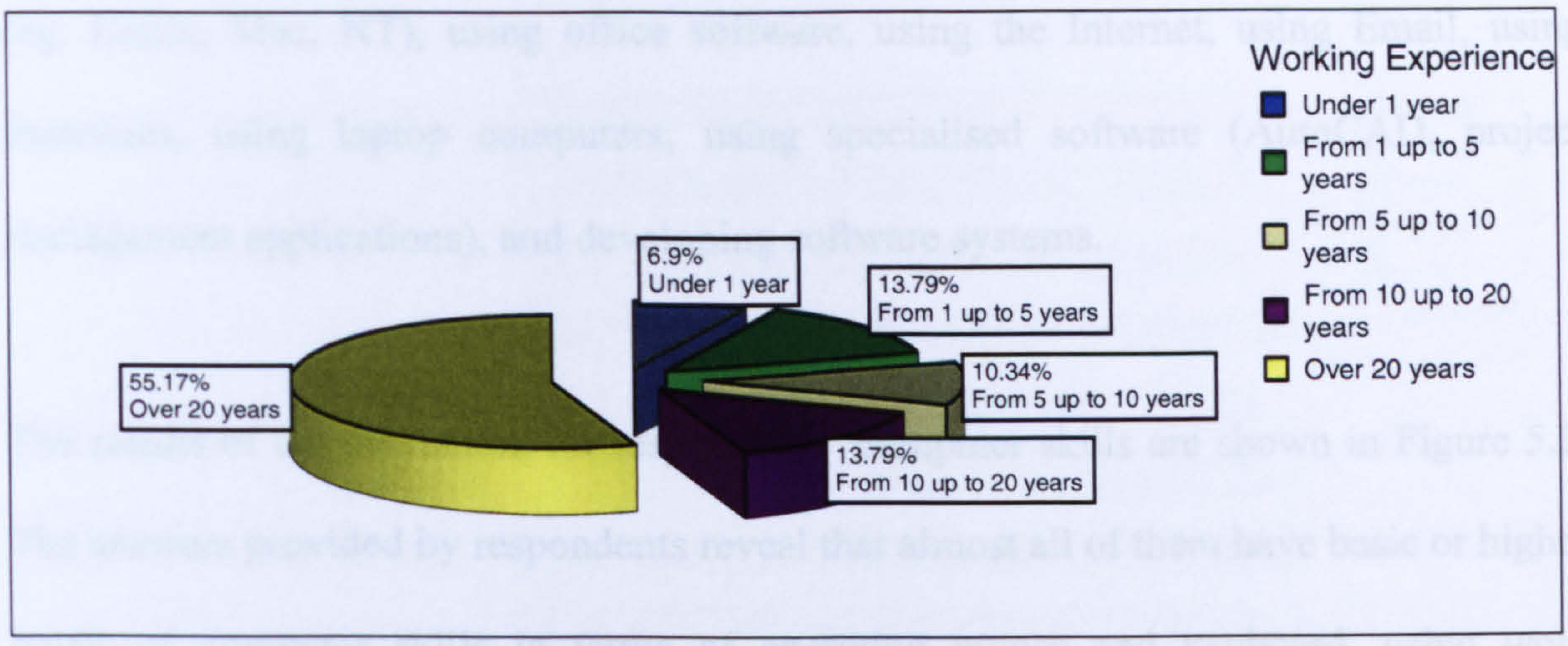


Figure 5. 2 Distribution of working experience among the respondents surveyed

The above findings indicate that the surveyed respondents are construction domain experts who have considerable construction-related knowledge and work experience in the construction industry. As the target respondents of this survey are construction professionals, respondents' profiles analysed above indicated that the selected respondents satisfied the sample requirements for this survey.

5.3.2.2 Computing Skills of Respondents

Because this survey aims to investigate the mechanisms of construction information communication and users' perception for mobile computing, it requires respondents to have basic computer-related knowledge and abilities to use computers and networks. Therefore, it was necessary to evaluate the extent of respondents' computer skills. Because the survey was conducted through the Internet, this ensured that all respondents have computers and one or more means to access the Internet. In order to evaluate the extent of the IT ability in using computers and networks, respondents were asked to assess their current computer skills referring to the following aspects: using mouse and keyboard, using word processing software, using Windows or other operating systems (eg. Linux, Mac, NT), using office software, using the Internet, using Email, using databases, using laptop computers, using specialised software (AutoCAD, project management applications), and developing software systems.

The results of the evaluation for respondents' computer skills are shown in Figure 5.3. The answers provided by respondents reveal that almost all of them have basic or higher levels of computer skills in terms of operating mouse and keyboard, using word processing software, using operating systems and office software. Only 3% of them indicate that they have poor skills in operating a mouse and keyboard, 7% have poor skills in using word processing software, in using operating systems 7% have poor skills and 3% indicated they had no skill, and 3% of respondents have difficulty in operating office software. 97% of respondents state that they have basic or higher skills in using the Internet and only 3% of them have poor Internet skills. All respondents have basic or higher skills in using Email. In using databases, 3% of them have no skills and 14% have poor skills. 28% of respondents state that they have excellent skills in using a laptop computer, 34% of them have good skills and 14% have basic skills. The specialised software in this survey refers to AutoCAD and project management applications. 93% of respondents have basic or higher ability in using these types of application software. Nearly half of respondents cannot design software.

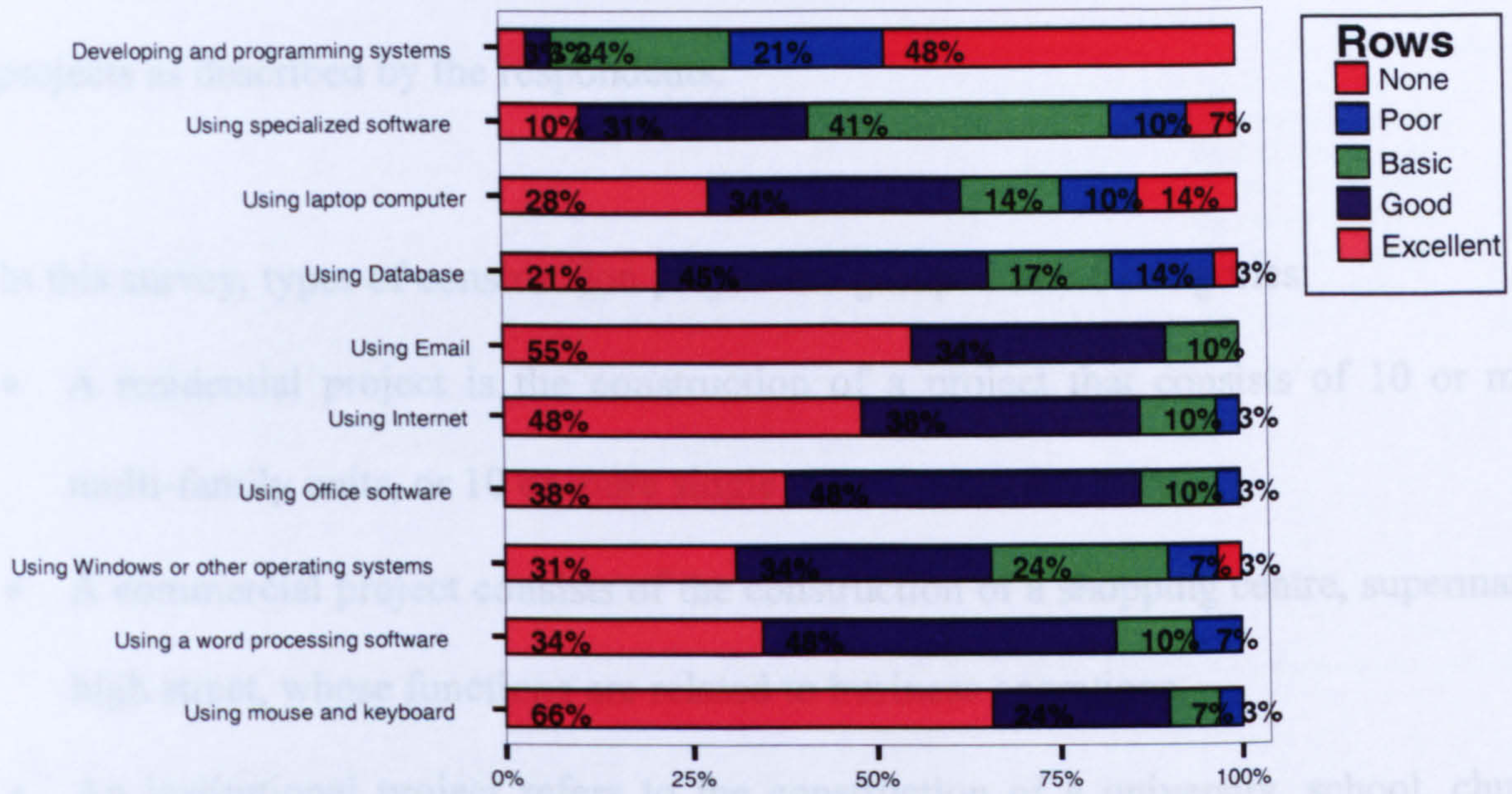


Figure 5. 3 Proportion of respondents in the level of different kinds of computer skills

The above results demonstrate that respondents are construction domain experts rather than IT domain experts, because only around a quarter of them have basic or higher programming skills. However, they have sufficient computer and network related knowledge to use Information Technology as a tool to assist them in their work.

5.3.2.3 Project Profiles

In this survey, respondents were asked to describe the last project in which they had been involved, which included project type, value, duration, and construction site type. Then, the following questions in this survey were in accordance with the specific projects described in this section and respondents were required to answer the questions based on the last project in which they were involved. The restriction of survey questions to a specific project ensures this survey is project-oriented, which means that the answers of an individual respondent reflect the circumstances of one specific project.

Therefore, it is necessary to investigate and analyse the profiles of these specific projects as described by the respondents.

In this survey, types of construction project are grouped into 6 categories:

- A residential project is the construction of a project that consists of 10 or more multi-family units, or 10 or more single room occupancy units.
- A commercial project consists of the construction of a shopping centre, supermarket, high street, whose functions are related to business operations.
- An institutional project refers to the construction of a university, school, church, government building, or hospital.
- An industrial project is the building of the factory, plant, and manufactory work shop.
- A highway project includes the construction of a road, motorway, bridge or railway.
- A heavy project includes the construction of the dam and airport.

Figure 5.4 shows the proportion of the types of construction projects provided by respondents. The maximum number of a particular project type is the commercial project (31%) and the second maximum number of a type is the heavy project (24.1%). Other types of projects consist of residential projects (17.2%), highway projects (10.3%), and industrial projects (6.9%). Only 3.4% of respondents indicated that their last projects were rail projects or tunnelling projects. Results show that the projects surveyed covered most construction project types.

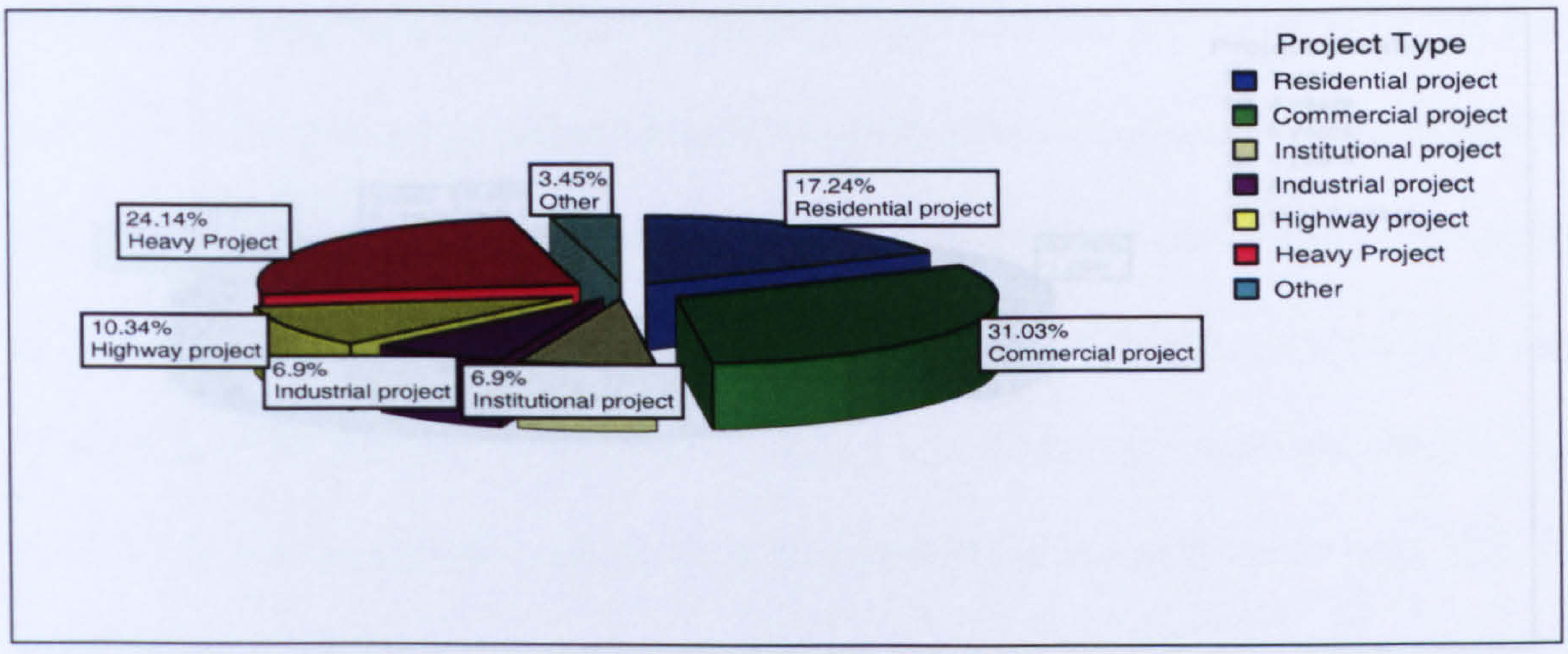


Figure 5. 4 Proportion of project types

Another characteristic of a project is the project value. Figure 5.5 shows that 41.4% of projects provided have an investment of over 10 millions of pounds, which indicates that nearly half the projects have a large financial investment.

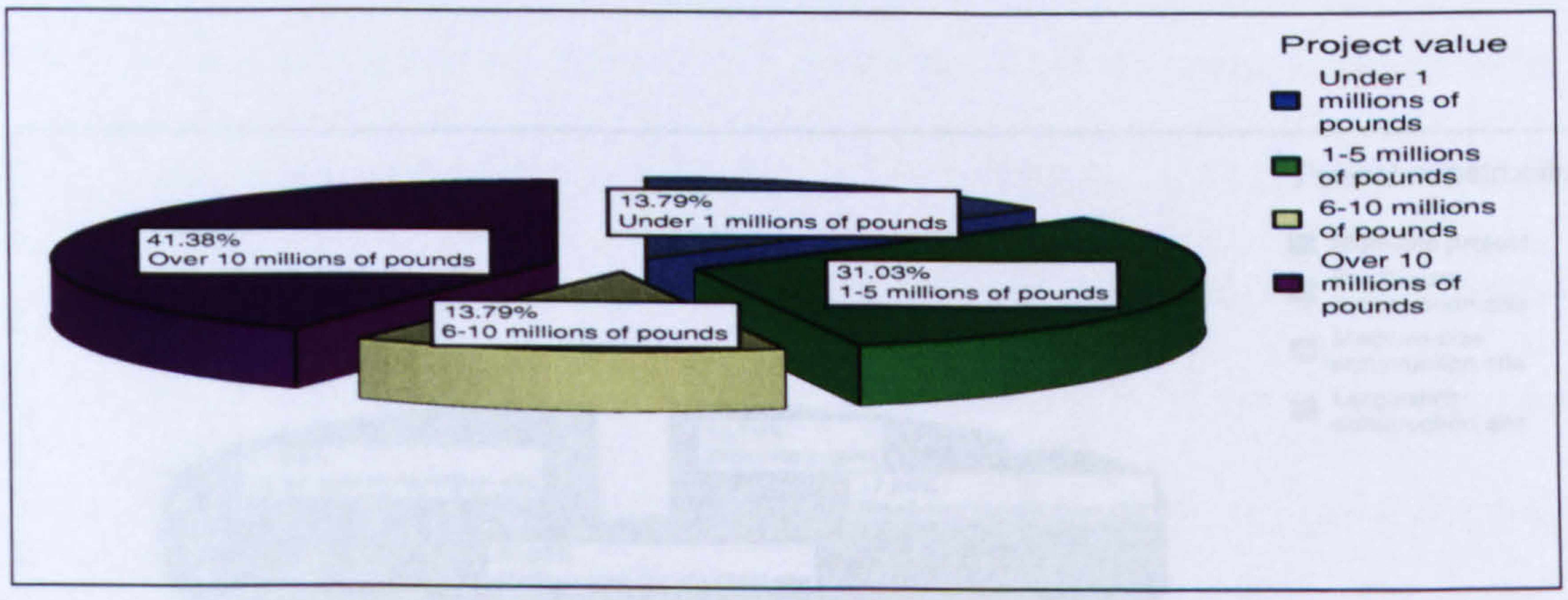


Figure 5. 5 Proportion of the value of project

Figure 5.6 shows the proportion of projects provided by respondents with project durations. Over 82% of projects had a construction duration of 1 year (34.5%) and 2 years (48.3%).

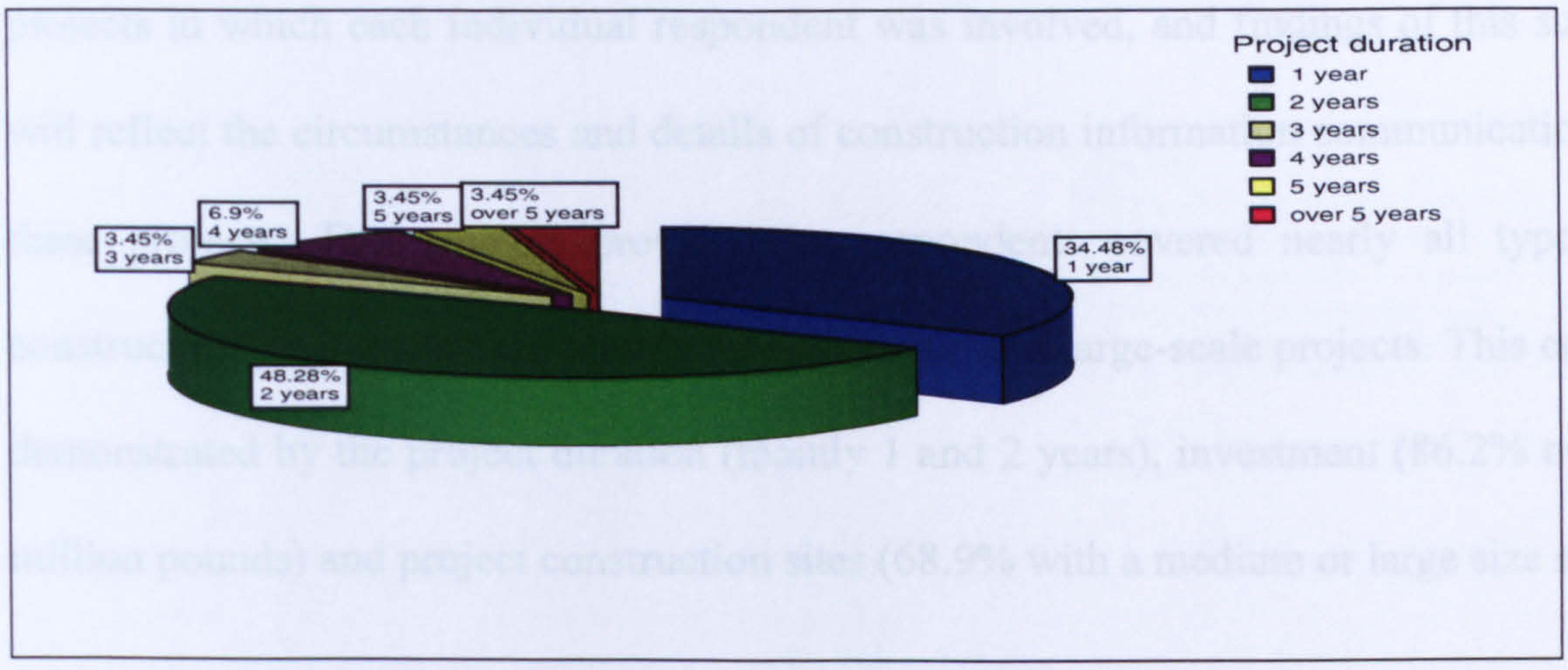


Figure 5. 6 Proportion of the duration of project

Because this survey aims to reveal information about communication on construction sites, the type of construction site is another important feature when describing project profiles. Most sites were medium-size (37.9%) or large-size (31%) construction sites with 13.8% of projects having more than one construction site (Figure 5.7).

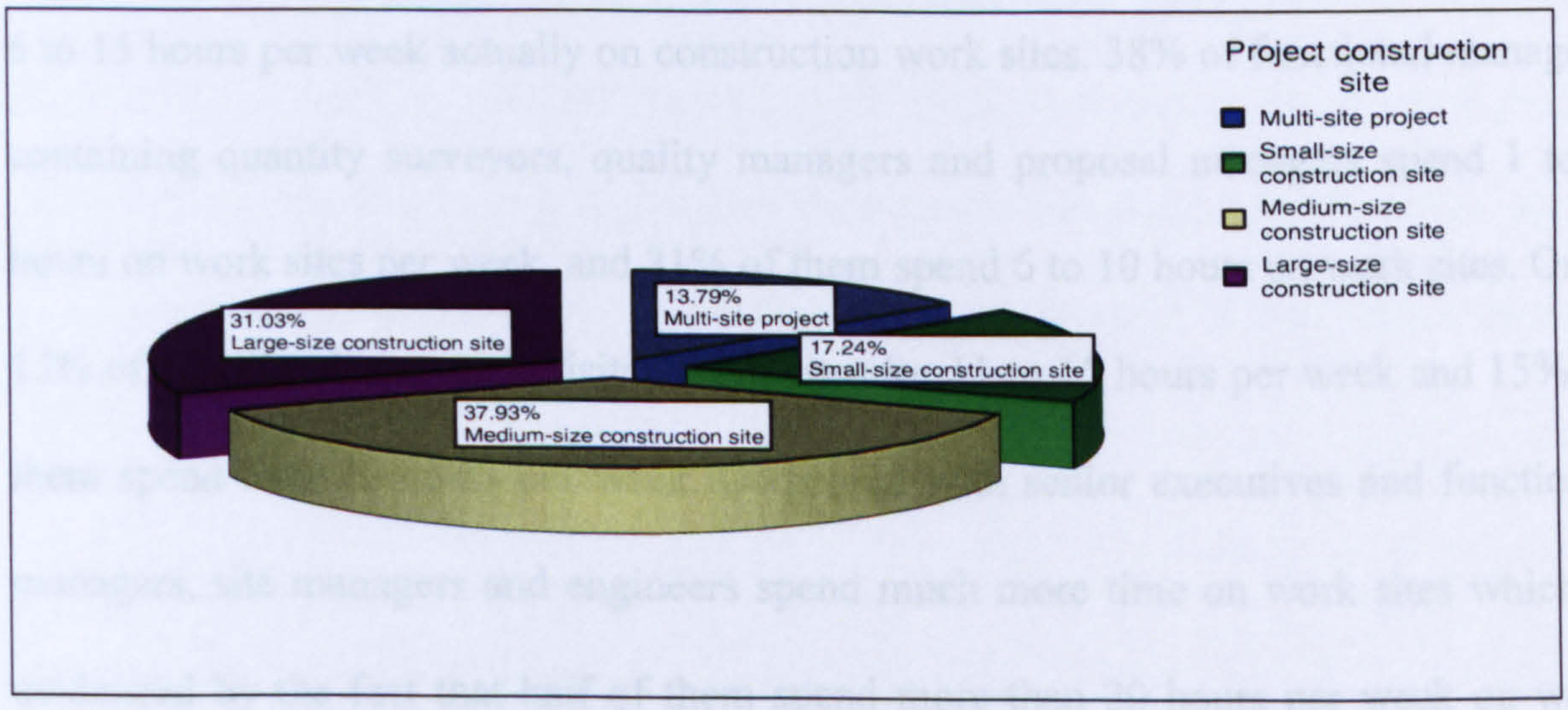


Figure 5. 7 Proportion of types of project construction site

As discussed in the previous section, the survey questions were based on the last projects in which each individual respondent was involved, and findings of this survey will reflect the circumstances and details of construction information communication on these projects. The projects provided by respondents covered nearly all types of construction projects and are mainly medium-scale and large-scale projects. This can be demonstrated by the project duration (mainly 1 and 2 years), investment (86.2% over 1 million pounds) and project construction sites (68.9% with a medium or large size site).

5.3.2.4 On-site Time of Respondents

Construction personnel frequently need to visit construction work sites during project construction. In this survey, respondents were asked to answer how many hours per week they spent on construction work sites (not in site offices) in the last project in which they had been involved. Figure 5.8 shows the results. From this figure, half of the senior executives spend no more than 5 hours per week on work sites and others spend 6 to 15 hours per week actually on construction work sites. 38% of functional managers containing quantity surveyors, quality managers and proposal managers spend 1 to 5 hours on work sites per week, and 31% of them spend 6 to 10 hours on work sites. Only 15% of functional managers visited work sites for 11 to 15 hours per week and 15% of them spend over 20 hours per week. Compared with senior executives and functional managers, site managers and engineers spend much more time on work sites which is evidenced by the fact that half of them spend more than 20 hours per week on work sites and 42% stay on work sites for 16 up to 20 hours per week.

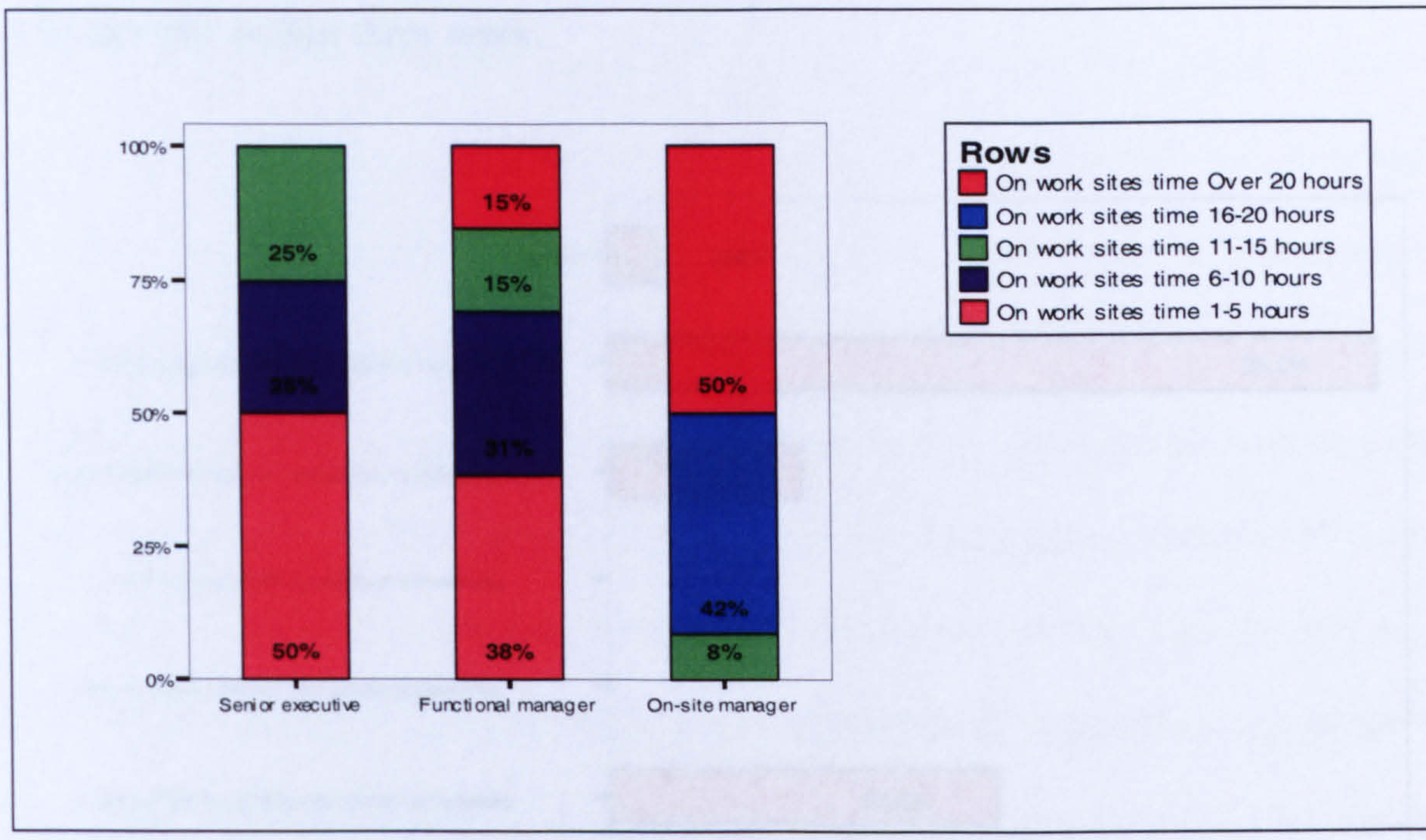


Figure 5. 8 Proportion of on-site time that construction personnel spent on construction work sites

The above findings indicate that the major work places of senior executives and functional managers are normally in head-offices, in which they perform and complete most of their work and responsibilities. On the other hand, although their major work place is the site office, they still need to visit work sites during the stage of project construction and are involved in some on-site construction processes. Moreover, on-site managers and engineers have to stay on work sites for the most of their time to perform construction activities.

5.3.2.5 On-site IT Support

This survey asked respondents what Information Technology tools they had used on construction sites in their last projects. Figure 5.9 shows that more than half of the respondents (55.2%) used laptop computers with connections to networks and 13.8% of them used laptops without any network connections; meanwhile, 27.6% of them used connected desktop computers in their last projects. However, none of respondents used a Pocket PC in their daily work.

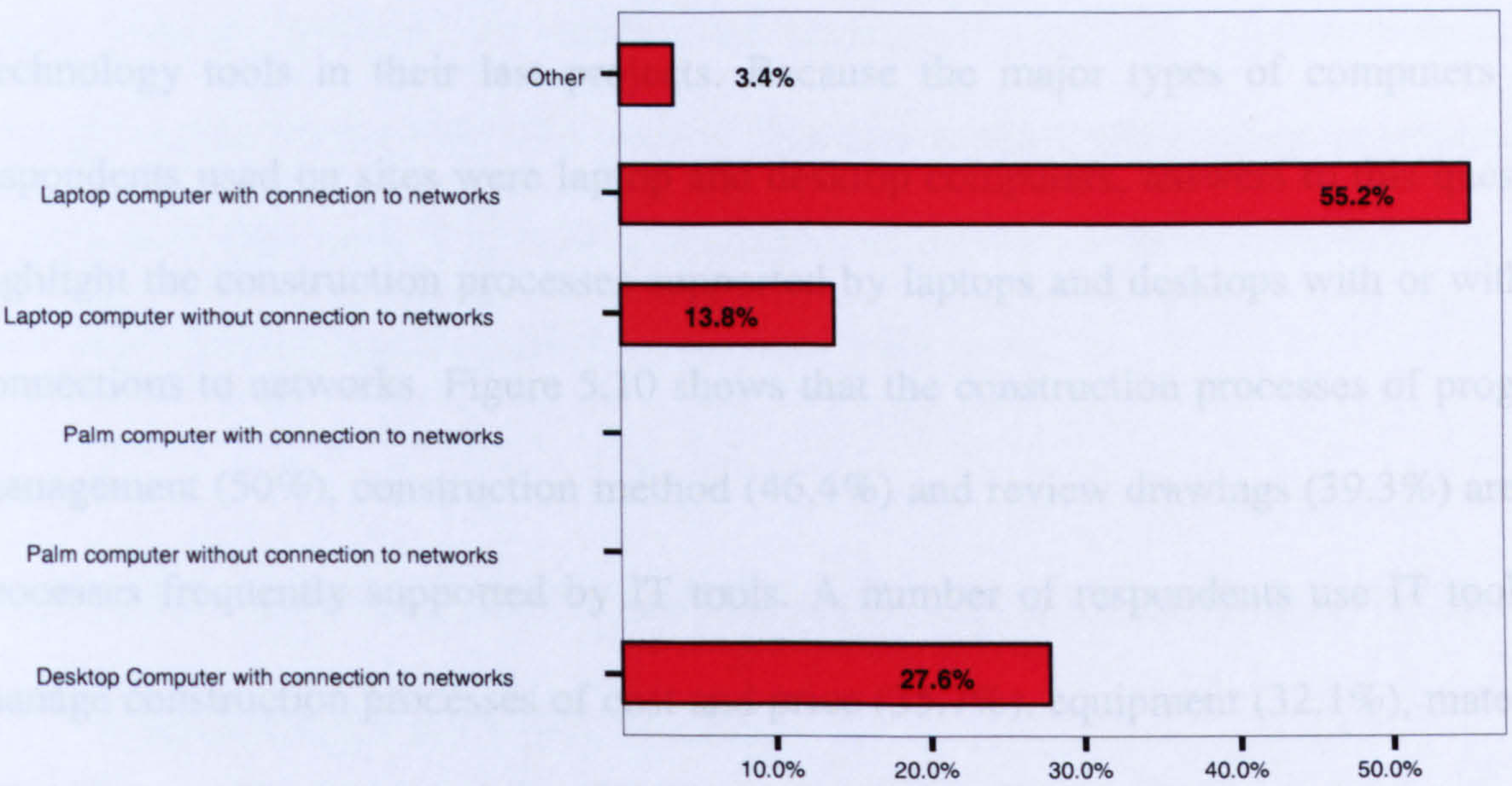


Figure 5. 9 Proportion of computers that respondents used in last projects

The findings clearly indicate that the major type of computer used on construction sites is the laptop computer with a connection to a network, but the use of Pocket PCs such as PDA (Personal Digital Assistant) and Tablet PC in daily work is not common on construction sites. Because laptop computers can only be used inside site offices and Pocket PCs can be held by construction personnel at all areas of construction work sites, these findings support the point of view that IT support including computers and networks have been extended to construction site offices and managerial personnel are normally equipped with fixed computers, but construction work sites do not have sophisticated IT support.

5.3.2.6 Construction Processes Supported by IT

Following the question about on-site IT support, respondents were asked to answer a question about which construction processes were supported by Information Technology tools in their last projects. Because the major types of computers that respondents used on sites were laptop and desktop computers, answers to this question highlight the construction processes supported by laptops and desktops with or without connections to networks. Figure 5.10 shows that the construction processes of progress management (50%), construction method (46.4%) and review drawings (39.3%) are the processes frequently supported by IT tools. A number of respondents use IT tools to manage construction processes of cost and price (35.7%), equipment (32.1%), materials (32.1%), specification review (32.1%), safety (32.1%) and labour (25%). A few respondents (14.3%) indicate that they use Information Technology tools for the management of other processes including the management of company information, customer care, project information, environmental, quality, risk, design, and site compliance.

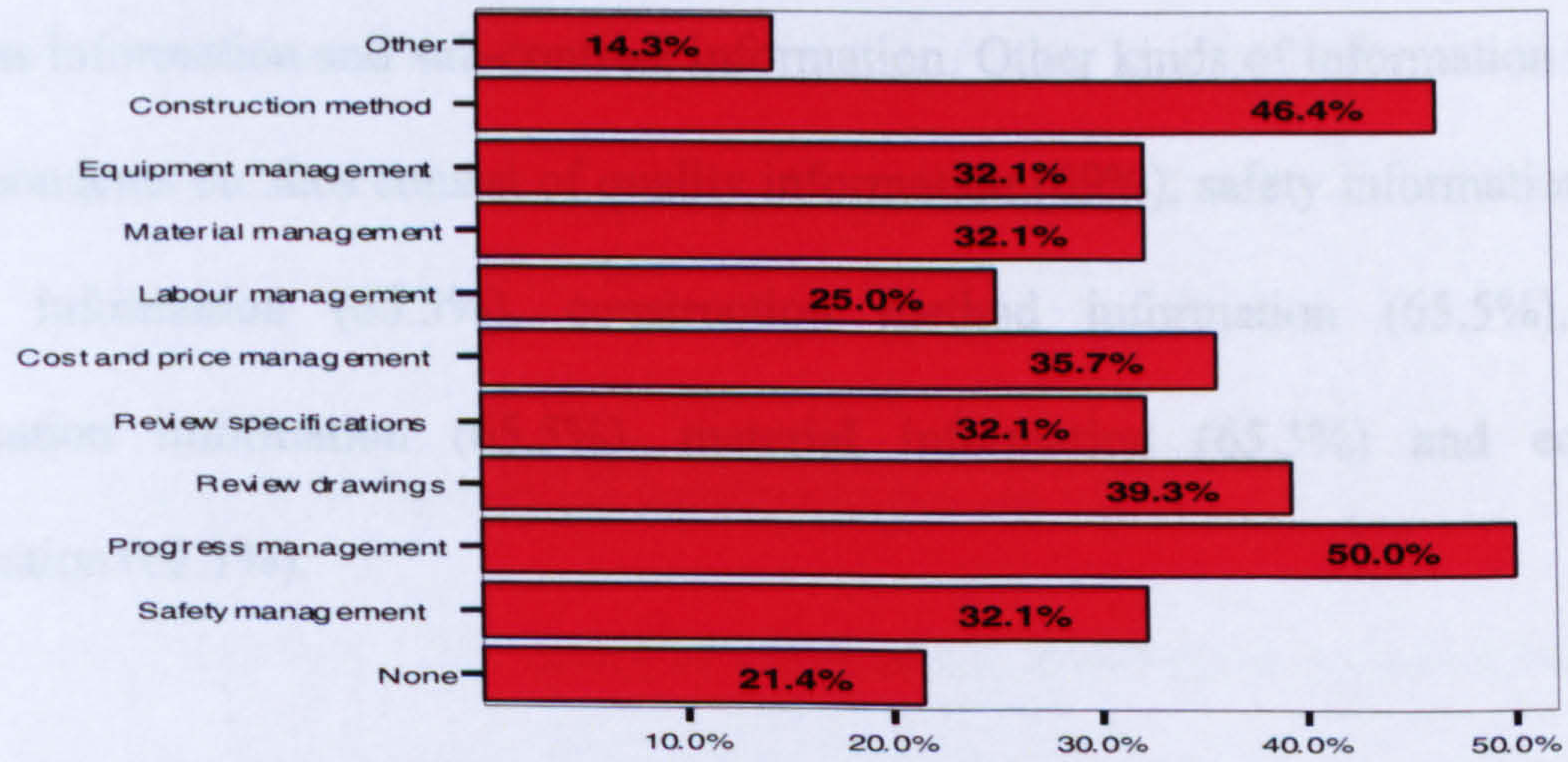


Figure 5. 10 Proportion of respondents who apply IT to perform different kinds of construction processes

Computers coupled with application software have been extensively applied to manage business processes on construction sites. The wide range of business processes supported by Information Technology suggests that there is plenty of efficient and helpful software available for construction managerial personnel to assist them in the management of construction information. This also supports the findings of respondent profiles that they have sufficient computer and network related knowledge to use Information Technology as a tool to assist their daily work.

5.3.3 THE MECHANISMS OF RETRIEVING CONSTRUCTION INFORMATION ON SITES

5.3.3.1 Received Construction Information on Sites

This survey focuses on information communication on construction sites and firstly identifies what information respondents receive on sites. Figure 5.11 shows that 89.7% of respondents indicate they receive drawings and specifications on construction sites during the stage of project construction. 86.2% of them obtain contract information, progress information and sub-contract information. Other kinds of information received by respondents on sites consist of quality information (69%), safety information (69%), labour information (65.5%), construction method information (65.5%), design clarification information (65.5%), material information (65.5%) and equipment information (62.1%).

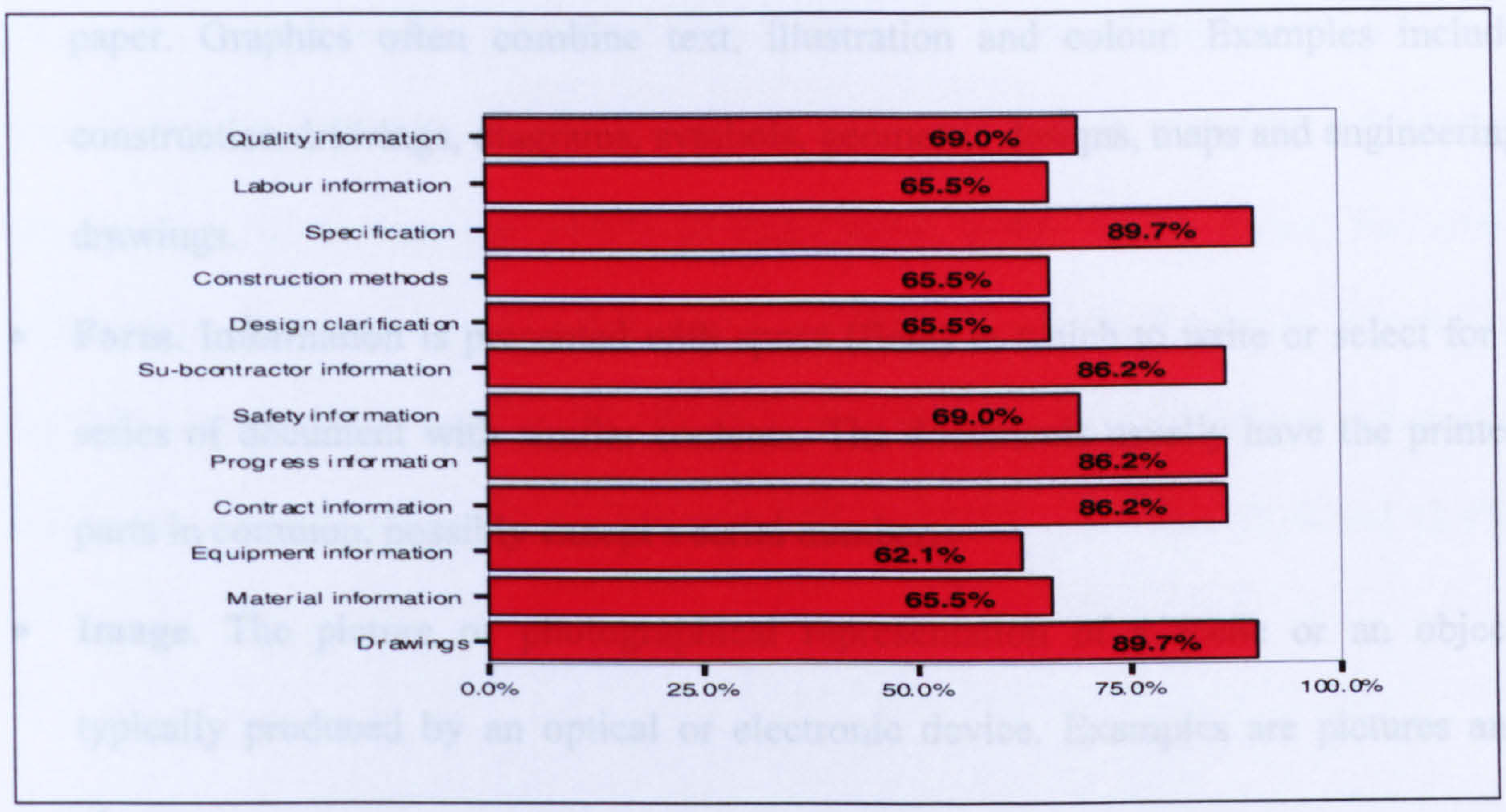


Figure 5. 11 Proportion of construction information that respondents received on sites

The above findings reveal that construction sites are information intensive environments, in which construction personnel receive many different types of construction information during the project construction stage. This also indicates that there is a need for construction personnel to use IT tools to achieve effective management of information. The most important information received on sites is drawings because nearly all respondents select drawings as the information they need in their daily work, which supports the findings in the case studies (Chapter 5.3.2).

5.3.3.2 Nature of Received Information on Sites

In this part of the survey, the nature of construction information is considered in terms of the formats of text, graphic, form, image and verbal.

- **Text**. Information is presented by written or printed words.

- **Graphic.** Information is presented by visual representations on computer screen or paper. Graphics often combine text, illustration and colour. Examples include construction drawings, diagrams, symbols, geometric designs, maps and engineering drawings.
- **Form.** Information is presented with space (field) in which to write or select for a series of document with similar contents. The documents usually have the printed parts in common, possibly except a serial number.
- **Image.** The picture or photographical representation of a scene or an object, typically produced by an optical or electronic device. Examples are pictures and photos.
- **Verbal.** Information is communicated through verbal communication.

Construction information was grouped into 12 categories and presented to respondents who could point out the format for each category of construction information they received on sites. This question is a multi-option question where respondents can select more than one type of format for each category of construction information. For example, the respondent can select the formats of graphic and image for construction drawings. The proportion of the formats for a particular information category indicates the percentage of total respondents who select the format type for this information category. All collected data was analysed and calculated by SPSS.

Figure 5.12 shows the proportion of respondents who receive construction information with different formats on sites. The results show that the major formats of drawings are graphic (96.4%) and image (39.3%). For other types of information, 88.5% of respondents receive material information in the format of text and 87% of them select text as the major format for equipment information. Additionally, 88.9% of respondents point out that they receive progress information in the format of graphic and 59.3% of them select text. 96.3% of respondents state that the format of safety information received on site is text and 55.6% of them select verbal as the format for safety information. For design clarification and construction methods, the major formats are text (81.5% and 96%) and graphic (81.5% and 60%) respectively. Labour and quality information have two main formats of text (80% and 92%) and verbal (60% and 42.9%).

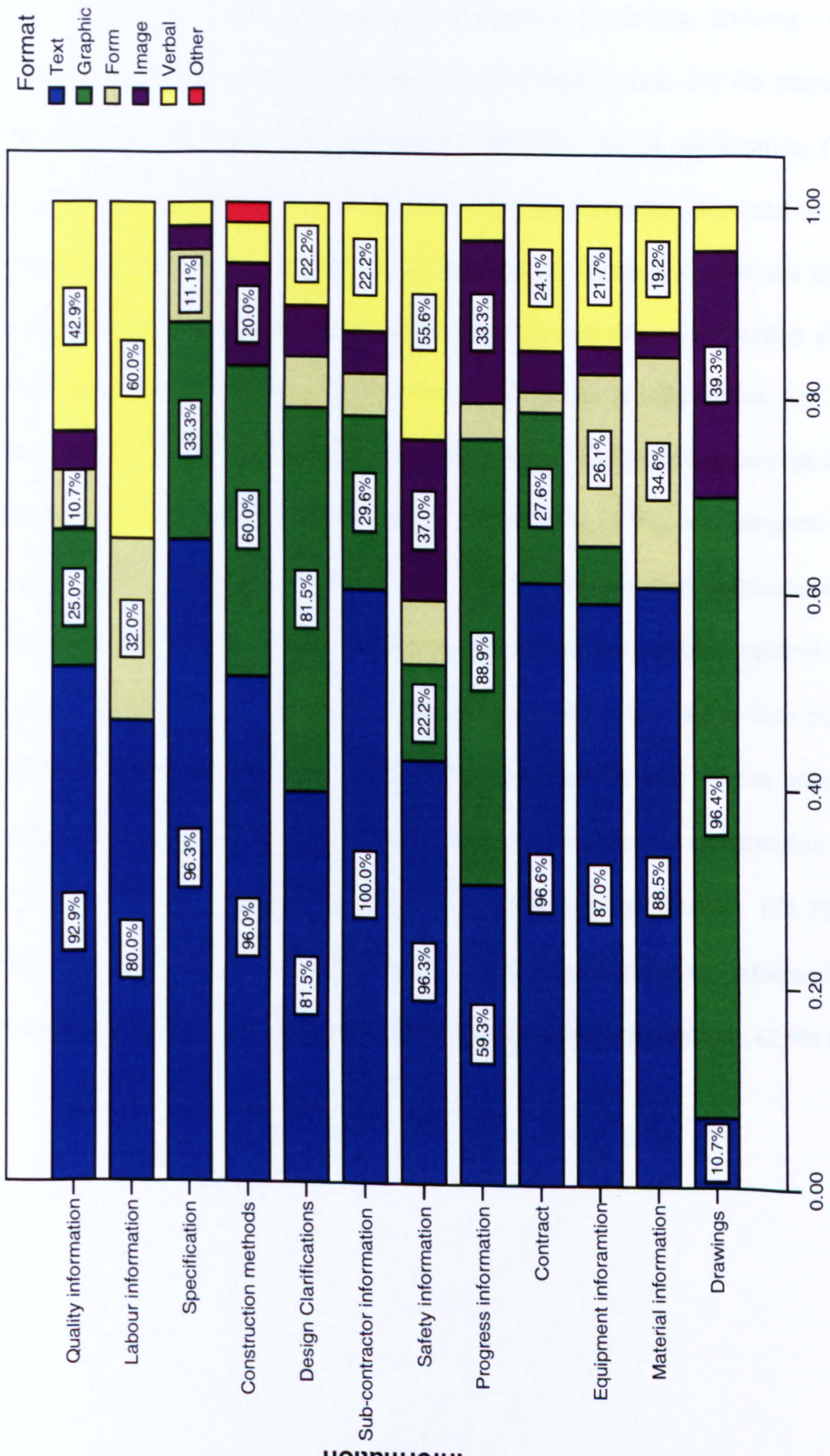


Figure 5. 12 Proportion of respondents who received construction information with different kinds of formats on sites

Figure 5.13 shows the proportion of all types of information received on sites with different formats. From this figure, information excluding drawings received on construction sites are mostly presented and described by text. For the purposes of clear and direct-viewing, progress information (88.9%), design clarification (81.5%) and construction methods (60%), in addition to text, are normally presented by graphic that is the second highest occurring form of information formats. The format of form is not widely used to display received construction information on construction sites, because 'form' has only 7.36% of total responses for all kinds of information, see Figure 5.13. From Figure 5.12 and Figure 5.13, only a few types of information contain the format of image, such as drawings (39.3%), safety information (37%), and progress information (33.3%). The format of 'verbal communication' means that respondents may have conversations with other construction personnel in order to obtain required information. The various methods of conversation consist of phone calls, face to face exchanges and meeting. Findings show that verbal communication is one of the more important supplemental methods for construction personnel to receive construction information such as material information (19.2%), equipment information (21.7%), contract information (24.1%), safety information (55.6%), sub-contractor information (22.2%), design clarifications (22.2%), labour (60%) and quality information (42.9%).

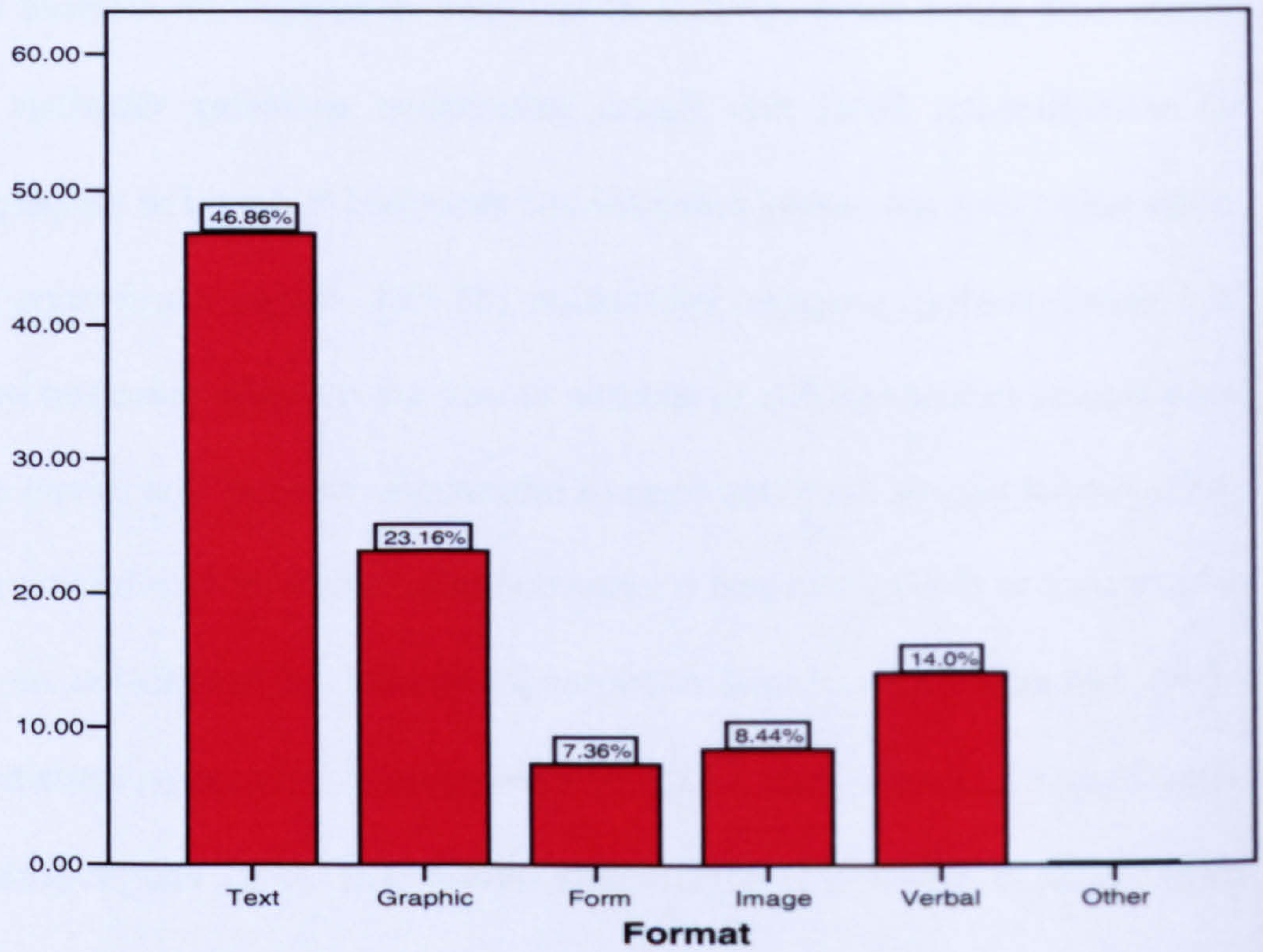


Figure 5. 13 Proportion of total responses for all types of information received on sites with different formats

5.3.3.3 Sources of Received Information on Sites

Respondents were asked to indicate from whom or from where they received each type of information on construction sites. The original personnel or places from where respondents receive construction information consist of the supervisor, client, consultant, design team, sub-contractor, engineer, supplier, project manager, quantity surveyor and other.

- **Supervisor**. The person who has the power and authority to give instructions or orders to respondents, to be held responsible for the work or actions of respondents, and to administrate discipline and penalties.
- **Client**. The person who is responsible for paying for the work contracted to designers and to the contractor.

- **Consultant.** The person who has an agreement with and provides design services and portions of the construction documents for the design team.
- **Design Team.** Designers who provide the client with the design of the project and the construction documents, based on the owner's needs.
- **Sub-contractor.** Separate business entities that provide labour, material, equipment, and occasionally second-tier subcontracts to complete a specific portion of the construction.
- **Engineer.** The person who is responsible for the coordination of shop drawings, submittals, layout, subcontractor organization, payment verification, and whatever duties are assigned by the construction administrator.
- **Supplier.** The person who supplies a particular service or commodity.
- **Project Manager.** The person who is the responsible party to the owner for the success of the project and in charge of all of the Construction Management employees on the project.
- **Quantity Surveyor.** The person who attempts to forecast and evaluate the design in economic terms both on an initial and life-cycle cost basis, prepares much of the tendering documentation used by contractors and plays an accounting role during the construction period.

Figure 5.14 shows the proportion of respondents who received construction information on sites from different sources. From the analysis, 77.8% of respondents receive drawings from the design team, 55.6% of them receive drawings from the consultant, and 51.9% from the sub-contractor. Material information is mostly transferred from the supplier (52%), the project manager (44%) and the quantity surveyor (44%). For equipment management information, in addition to the supplier (50%), the project manager (50%) and the quantity surveyor (46.2%), more than half (61.5%) of respondents receive them from the sub-contractor. Most respondents receive contracts from the client (72.4%), the consultant (72.4%), the design team (41.4%), and the project manager (58.6%). 66.7% of respondents receive progress information from the project manager and 44.4% of them receive this information from the supervisor. Safety information is mostly transferred from three places: the supervisor (59.3%), the sub-contractor (55.6%) and the project manager (70.4%). 71.4% of respondents receive sub-contractor information from the sub-contractor, 53.6% of them receive this information from the project manager and 46.4% from the quantity surveyor. For design clarification, most respondents (84.5%) receive them from the design team and half of them (53.8%) receive this information from the consultant. Construction methods are mostly transferred from the project manager (61.5%), the sub-contractor (50%), the engineer (46.2%), and the design team (42.3%). More than half of respondents (65.4%) receive specification from the consultant and the design team, and half of them receive this information from the project manager. Labour information is mostly transferred from three original places: the supervisor (62.5%), the sub-constructor (58.3%), and the project manager (45.8%). Finally, 67.9% of respondents receive quality information from the project manager and half of them receive it from the supervisor.

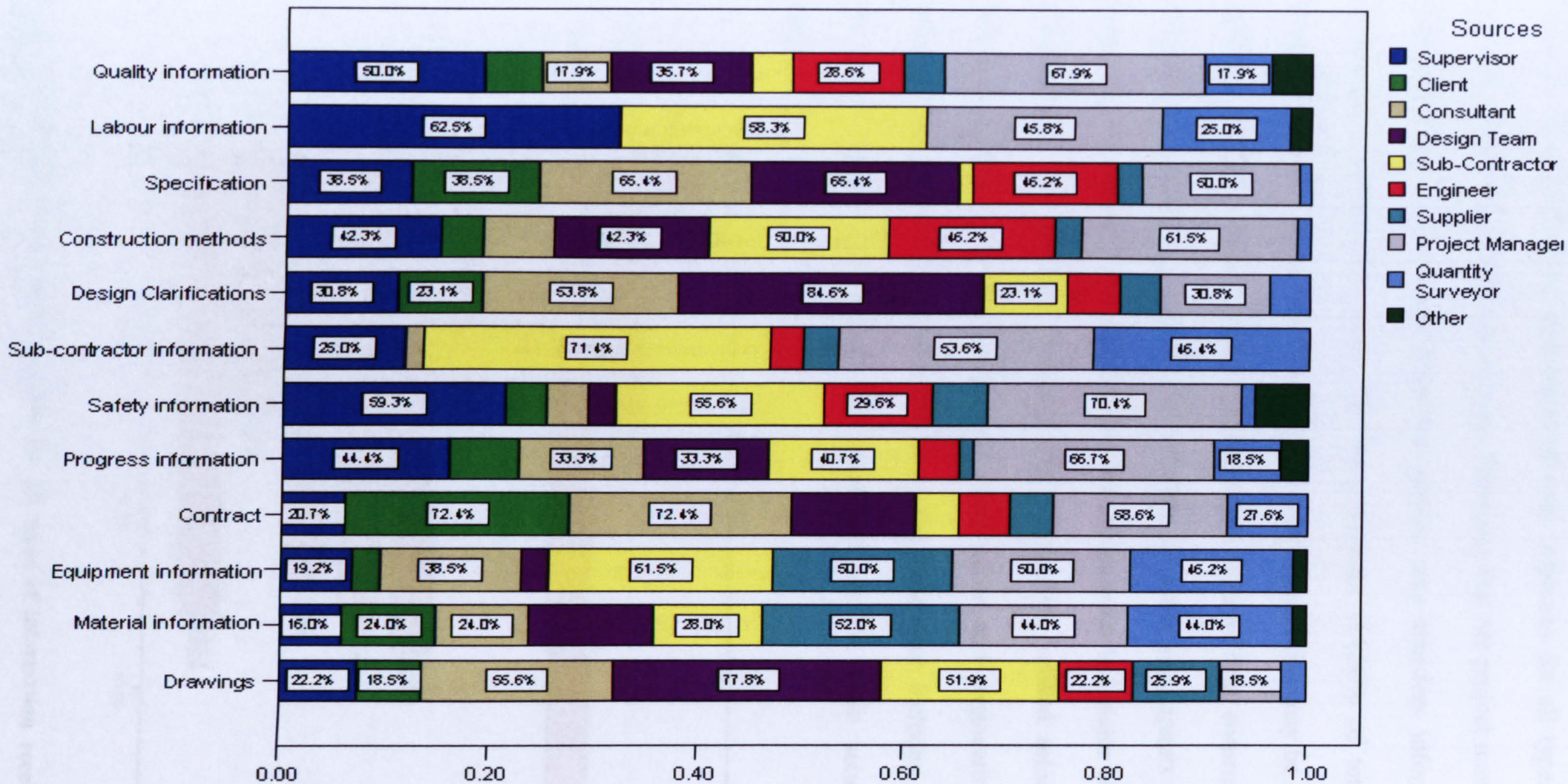


Figure 5. 14 Proportion of respondents who received construction information on sites from different sources

Figure 5.15 presenting the proportion of total responses for all types of information received on sites from different sources, illustrates that the project manager (18.71% of total responses) is the most important person who transfers information to other personnel on construction sites. The sub-contractor (14.06% of total responses) is another important source for the transfer of information. This may be because the sub-contractor needs to transfer related information, such as their construction processes, construction activities, progress and schedule to other participants involved in the project for the purpose of collaboration. The design team is a major element that takes responsibility for providing technical and engineering related information such as drawings, contracts, design clarification, construction and engineering methods, and specifications. Information transferred from the supervisor includes progress, safety, labour and quality. The client and consultant are the main sources of contract information.

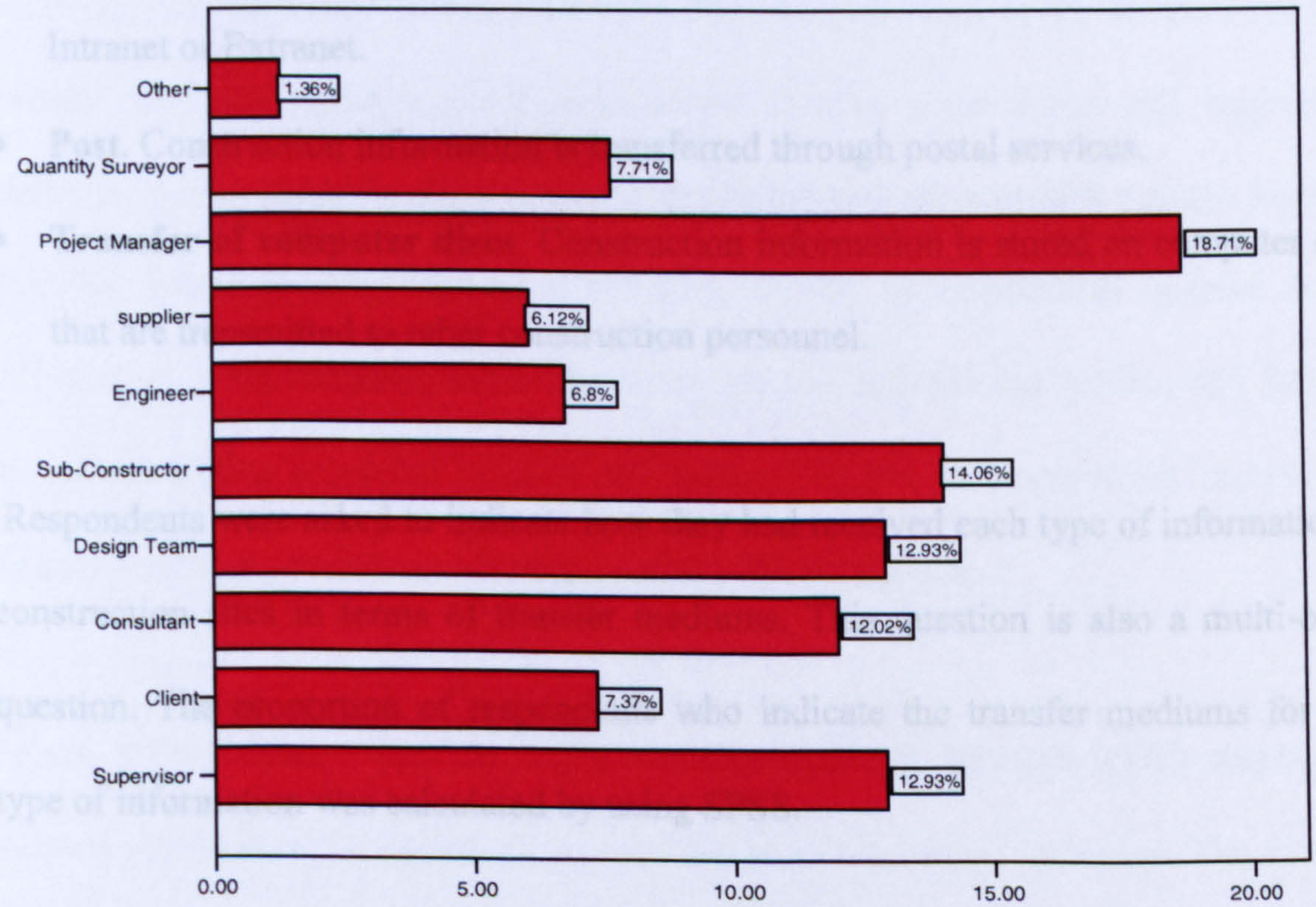


Figure 5.15 Proportion of total responses for all types of information received on sites from different sources

5.3.3.4 Transfer Mediums of Received Information on Sites

Transfer mediums used by construction personnel to transfer information on construction sites are grouped into 9 categories including meetings, one-to-one pass, fax, telephone, email, Intra/Extranet, post, transfer of computer discs, and other.

- **Meeting.** Respondents receive, transfer or communicate construction information in on-site meeting.
- **One-to-one Pass.** Respondents exchange construction documents with other construction personnel.
- **Fax.** Construction information is transferred through fax.
- **Telephone.** Respondents communicate construction information through telephone calls.
- **Email.** Construction information is transferred through sending emails.
- **Intra/Extranet.** Respondents receive or transfer construction information by Intranet or Extranet.
- **Post.** Construction information is transferred through postal services.
- **Transfer of computer discs.** Construction information is stored on computer discs that are transmitted to other construction personnel.

Respondents were asked to indicate how they had received each type of information on construction sites in terms of transfer mediums. This question is also a multi-option question. The proportion of respondents who indicate the transfer mediums for each type of information was calculated by using SPSS.

Figure 5.16 shows the proportion of respondents who received construction information on sites through different transfer mediums. From this figure, 77.8% of respondents indicate that they received drawings in meetings and 74.1% of them received drawings by post. This reveals that meetings and post are the most common methods of exchanging drawings. For transferring material information, most (73.1%) are via email, 61.5% are via the telephone, and 53.8% of them are via post. Equipment information is mostly transferred via email (65.4%), fax (50%) and post (50%). The meeting (69%), one-to-one pass (48.3%), email (58.6%) and post (55.2%) are the common transfer mediums through which most respondents receive contracts on construction sites. 65.4% of respondents indicate that they receive progress information in meetings, and 61.5% of them received this information via email. For transferring safety information to construction sites, 69% of respondents receive them in meetings, 61.5% receive them via email, and 61.5% are via post. Sub-contractor information is mostly received through meetings (64.3%), email (64.3%) and post (50%). 77.8% of respondents receive design clarifications in meetings, 55.6% received them via the telephone and 51.9% are via email. The meeting (76.9%), email (57.7%) and post (46.2%) are the three common transfer mediums through which respondents receive construction and engineering methods on sites. Specifications received by respondents are normally through meetings (55.6%), email (55.6%) and post (55.6%). 65.4% of respondents receive labour information in the meeting, half of them receive this information via fax, and 50% are via email. When receiving quality information, 67.9% of respondents receive this through meetings, 67.9% are via email and 46.4% are via post.

Figure 5.17 indicates that the major transfer mediums through which respondents receive information on construction sites are meetings, email and post. The fact that nearly all types of information are received through on-site meetings may indicate that on construction sites the meeting is the most important method for construction personnel to communicate and exchange information. The fact that the exchange of information via email has become a more common practice reveals that many construction documents are stored and transferred digitally, and IT tools including computers and networks have been widely applied in the management of information on construction sites. As a traditional method, the postal service is still an important information transfer method for construction personnel. Compared with email, Intra/Extranet is not widely utilised by respondents to retrieve or transfer information.

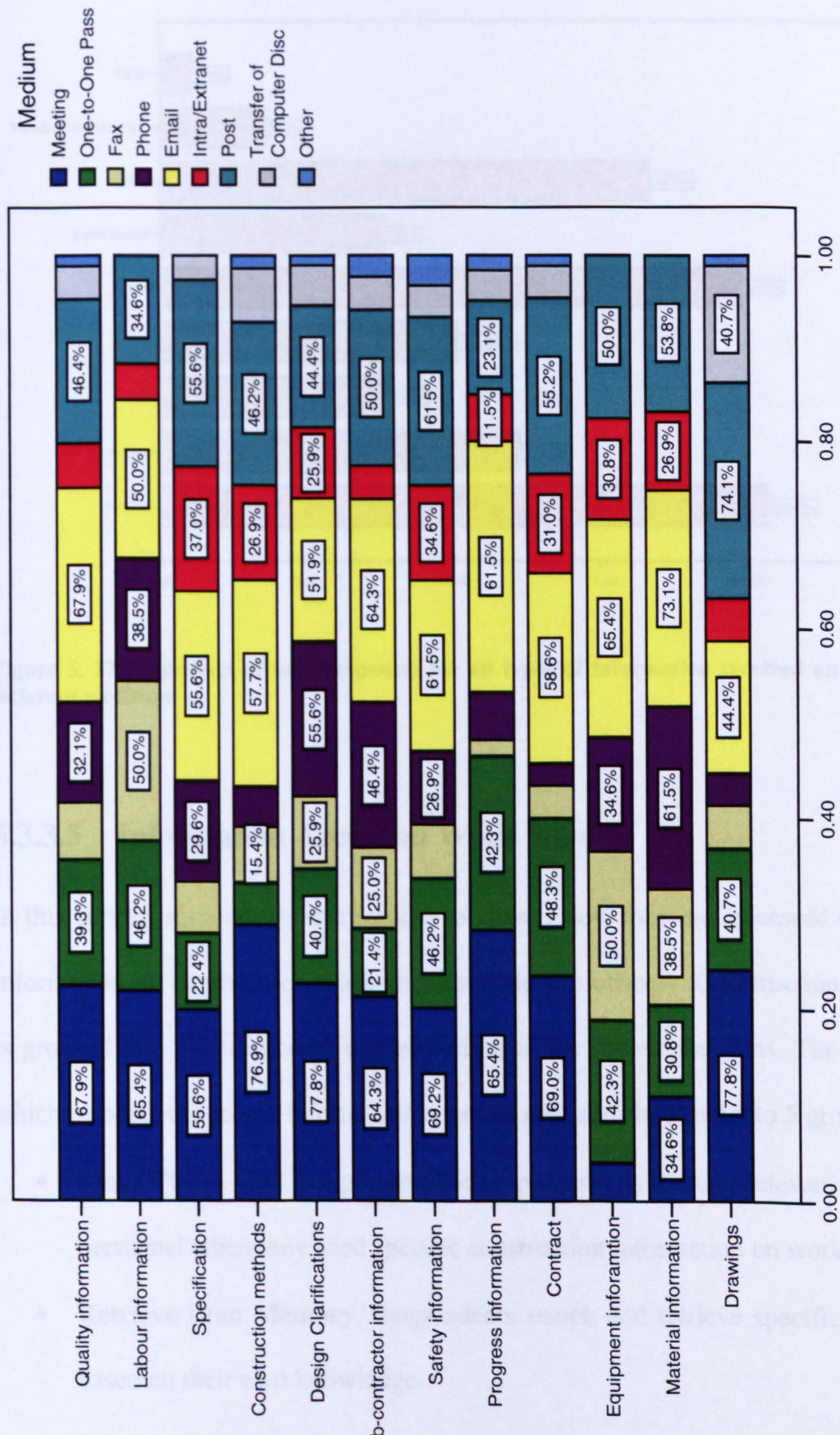


Figure 5. 16 Proportion of respondents who received construction information on sites through different transfer medium

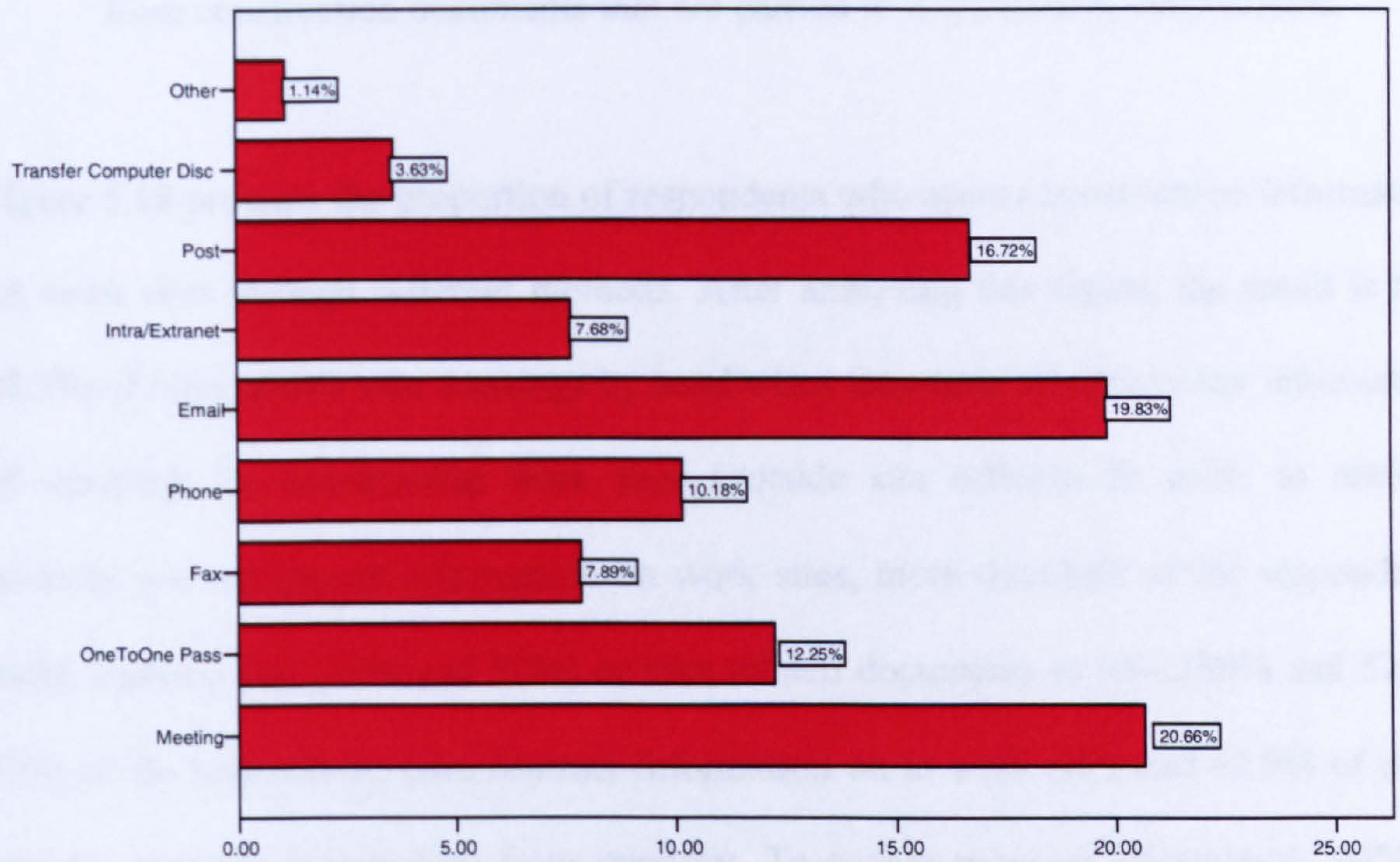


Figure 5. 17 Proportion of total responses for all types of information received on sites through different mediums

5.3.3.5 Information Access on Work Sites

In this survey, respondents were asked to answer how they had accessed each type of information on construction work sites (outside site offices). Construction information is grouped into 12 categories, corresponding to the above questions. The methods by which respondents access information on work sites are classified into 5 groups:

- **Make Phone Call**. Respondents make phone calls to other relevant construction personnel when they need specific construction information on work sites.
- **Retrieve** from **Memory**. Respondents search and retrieve specific information based on their own knowledge.
- **Retrieve from Notebook**. Respondents retrieve specific information from their notebooks.

- **Take Document by Hand.** Respondents search and view required information from construction documents that are carried to work sites by respondents.

Figure 5.18 presents the proportion of respondents who access construction information on work sites through different methods. After analysing this figure, the result is that 88.5% of respondents take drawings by hand when they need to retrieve the information of drawings on construction work sites (outside site offices). In order to retrieve material and equipment information on work sites, more than half of the respondents make a phone call (64% and 52%) or take related documents to sites.(60% and 52%). 75% of the respondents take contract information on to work sites and 42.9% of them retrieve contract information from memory. To access progress information, 64% of respondents retrieve from memory and 56% of them take progress files to sites. 69.2% of respondents retrieve safety information from memory and 53.8% of them make phone calls. Sub-contract information is normally transferred to work sites through making phone calls (63%), retrieving from memory (48.1%) and taking document by hand (44.4%). Making phone calls (69.2%) and taking document by hand (57.7%) are the most common methods used by respondents to retrieve design clarification. Retrieving from memory (64%) and making phone calls (56%) are mostly used for the retrieval of construction methods. 69.2% of respondents take specification to work sites and 64% of them make phone calls to obtain labour information. Quality information is normally retrieved from memory (63%) while on work sites.

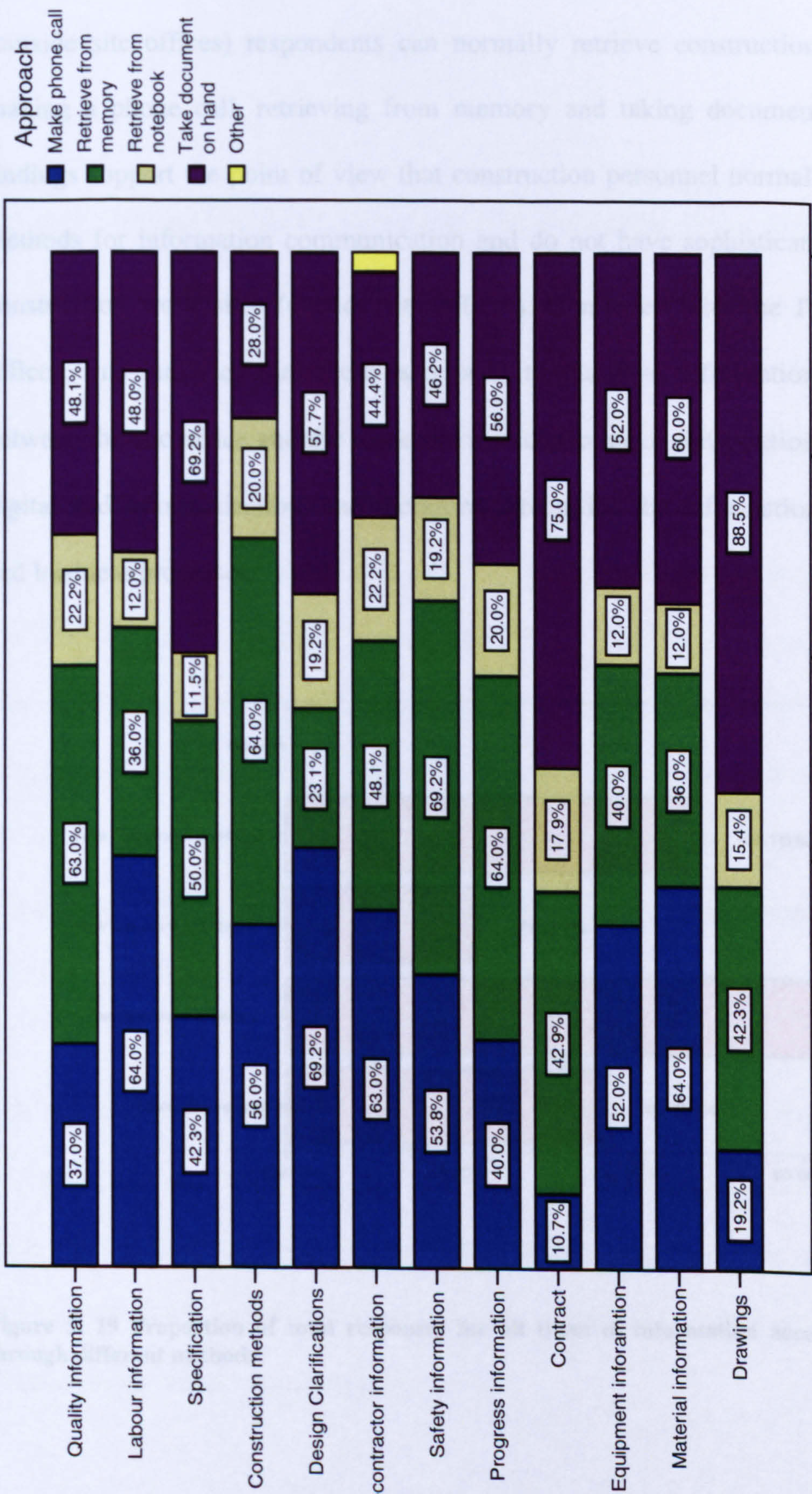


Figure 5. 18 Proportion of respondents who accessed construction information on work sites through different methods

In Figure 5.19, the proportion of total responses specifies that on construction work sites (outside site offices) respondents can normally retrieve construction information by making a phone call, retrieving from memory and taking documents by hand. The findings support the point of view that construction personnel normally use traditional methods for information communication and do not have sophisticated IT support on construction work sites (outside site offices). Compared with the IT support in site offices, this indicates that there is a need to integrate information communication between the site office and the work site in order to make construction work sites more digital and informatization, and therefore, streamline the information communication and business processes.

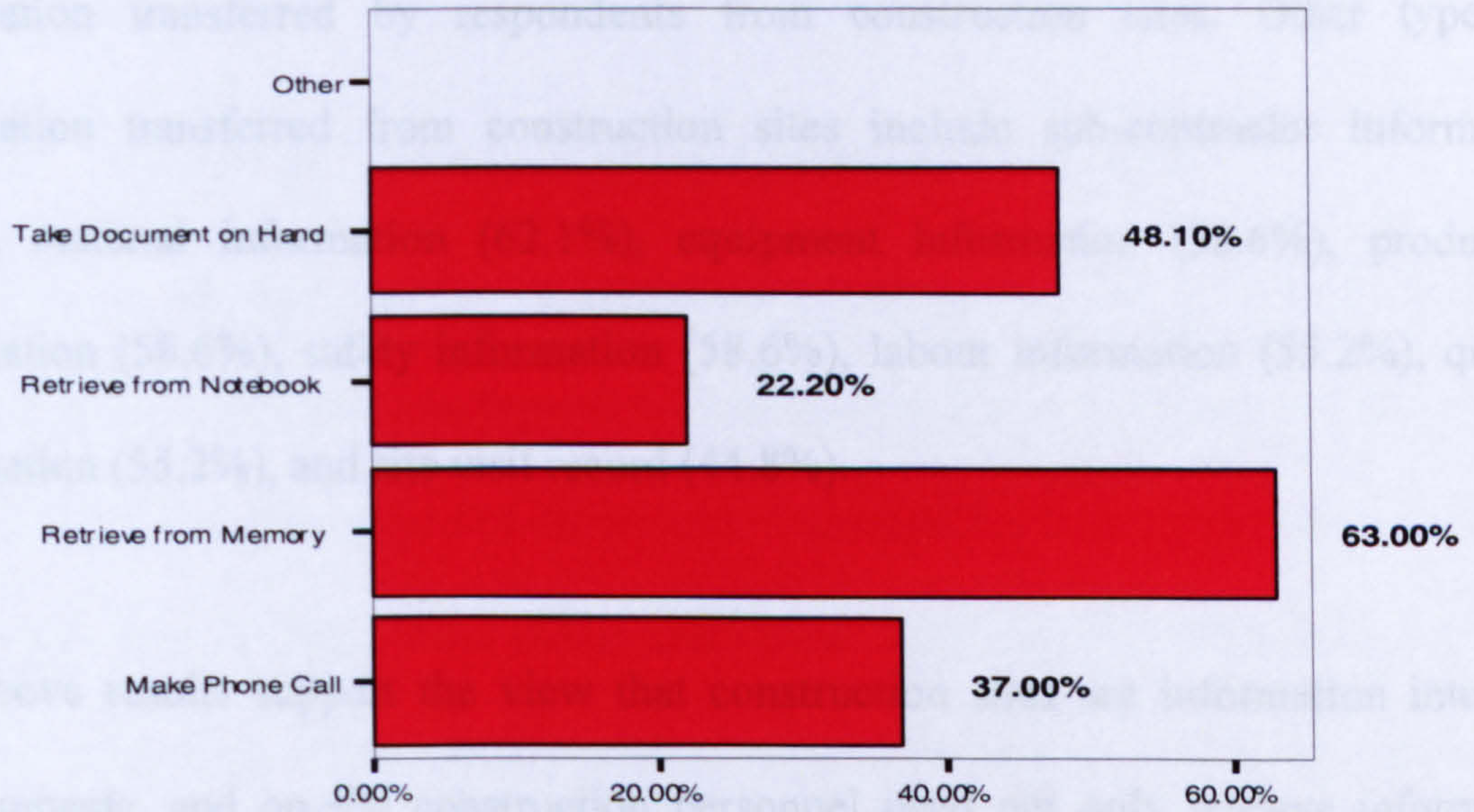


Figure 5. 19 Proportion of total responses for all types of information accessed on work sites through different methods

5.3.4 THE MECHANISMS OF TRANSFERRING CONSTRUCTION INFORMATION FROM SITES

5.3.4.1 Transferred Construction Information from Sites

In this part of the survey, respondents were asked to indicate which types of construction information were transferred from construction sites. Figure 5.20 shows the proportion of construction information transferred by respondents from construction sites. In this figure, 96.6% of respondents indicate they transfer Request For Information (RFI) from construction sites, 82.8% of them transfer progress information and 79.3% transfer schedule information. These are the most common types of information transferred by respondents from construction sites. Other types of information transferred from construction sites include sub-contractor information (69%), material information (62.1%), equipment information (58.6%), production information (58.6%), safety information (58.6%), labour information (55.2%), quality information (55.2%), and site visit record (44.8%).

The above results support the view that construction sites are information intensive environments, and on-site construction personnel need not only retrieve information from other sources but also transfer information from construction sites. Request For Information (RFI), progress information and schedule information are the major types of information transferred from sites.

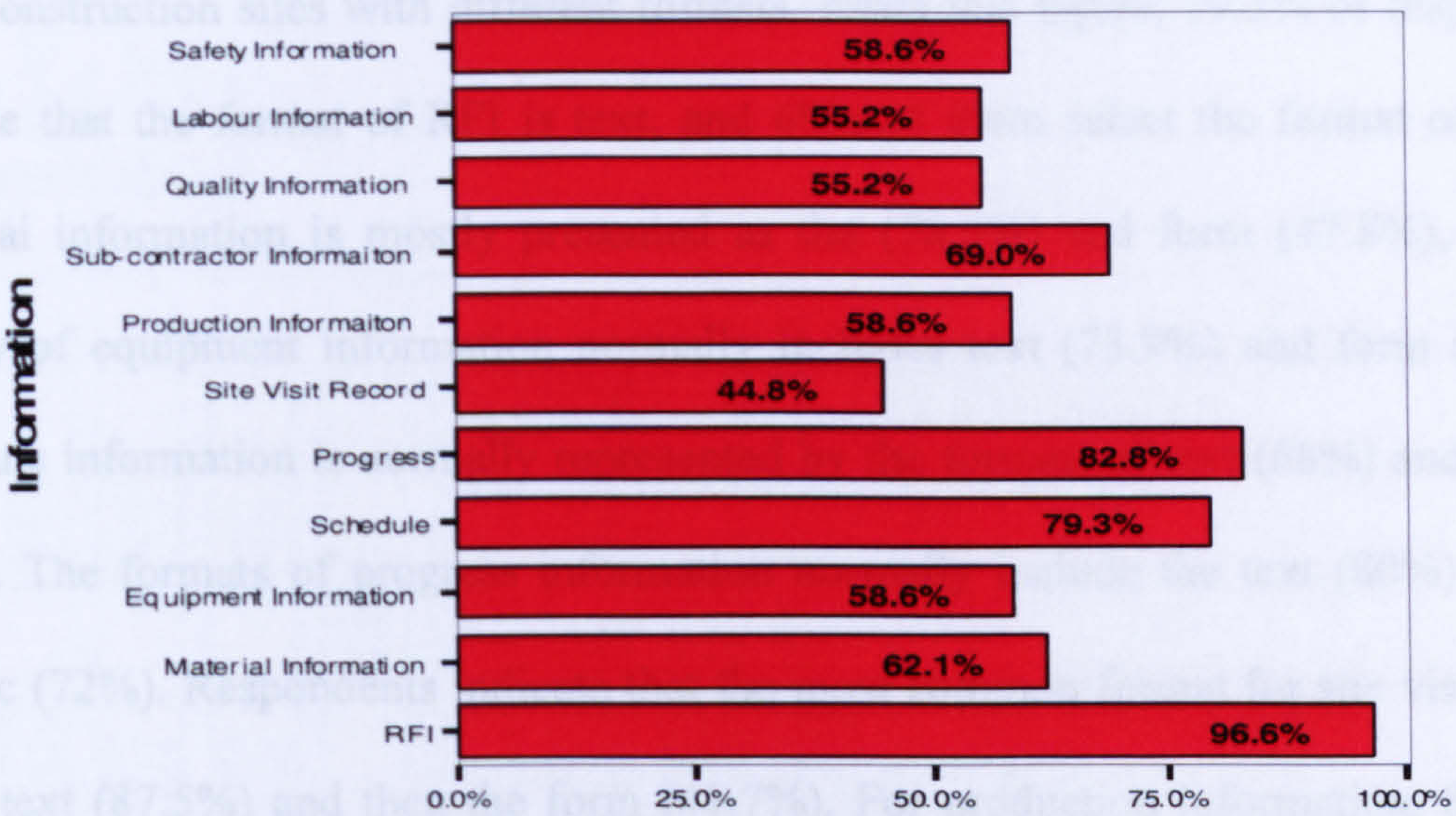


Figure 5. 20 Proportion of construction information that respondents transferred from sites

5.3.4.2 Nature of Transferred Information from Sites

In addition to the investigation of information formats received on construction sites, this survey also considers the formats of information that respondents transferred from construction sites. The nature of construction information is also considered as 5 types of formats: text, graphic, form, image and verbal. Construction information is grouped into 11 categories, which were presented to respondents who then pointed out the formats for each category of information they transferred from sites. This question is a multi-option question, which means that respondents can select more than one format for each type of information. For example, respondents can select the formats of text and Verbal for RFI. The proportion of the format for a particular type of information indicates the percentage of total respondents who select related formats for this type of information. All collected data was analysed by SPSS.

Figure 5.21 shows the proportion of respondents who transfer construction information from construction sites with different formats. From this figure, 79.3% of respondents indicate that the format of RFI is text, and 69% of them select the format of verbal. Material information is mostly presented as the (78.3%) and form (47.8%), and the display of equipment information normally includes text (73.9%) and form (47.8%). Schedule information is normally represented by the formats of text (68%) and graphic (60%). The formats of progress information normally include the text (80%) and the graphic (72%). Respondents indicate that the most common format for site visit record is the text (87.5%) and then the form (41.7%). For production information, 87.5% of respondents select the format of the text and 29.2% of them indicate the format of the form and the verbal. Sub-contractor information is normally transferred from sites in the formats of the text (88.5%), form (42.3%) and verbal (50%). The common formats of quality information consist of the text (88.5%), form (38.5%) and verbal (38.5%). The major format of labour information is text (87%). 83.3% of respondents indicate that the format of safety information is the text, 41.7% of them select the format of the form and 33.3% indicate the verbal format.

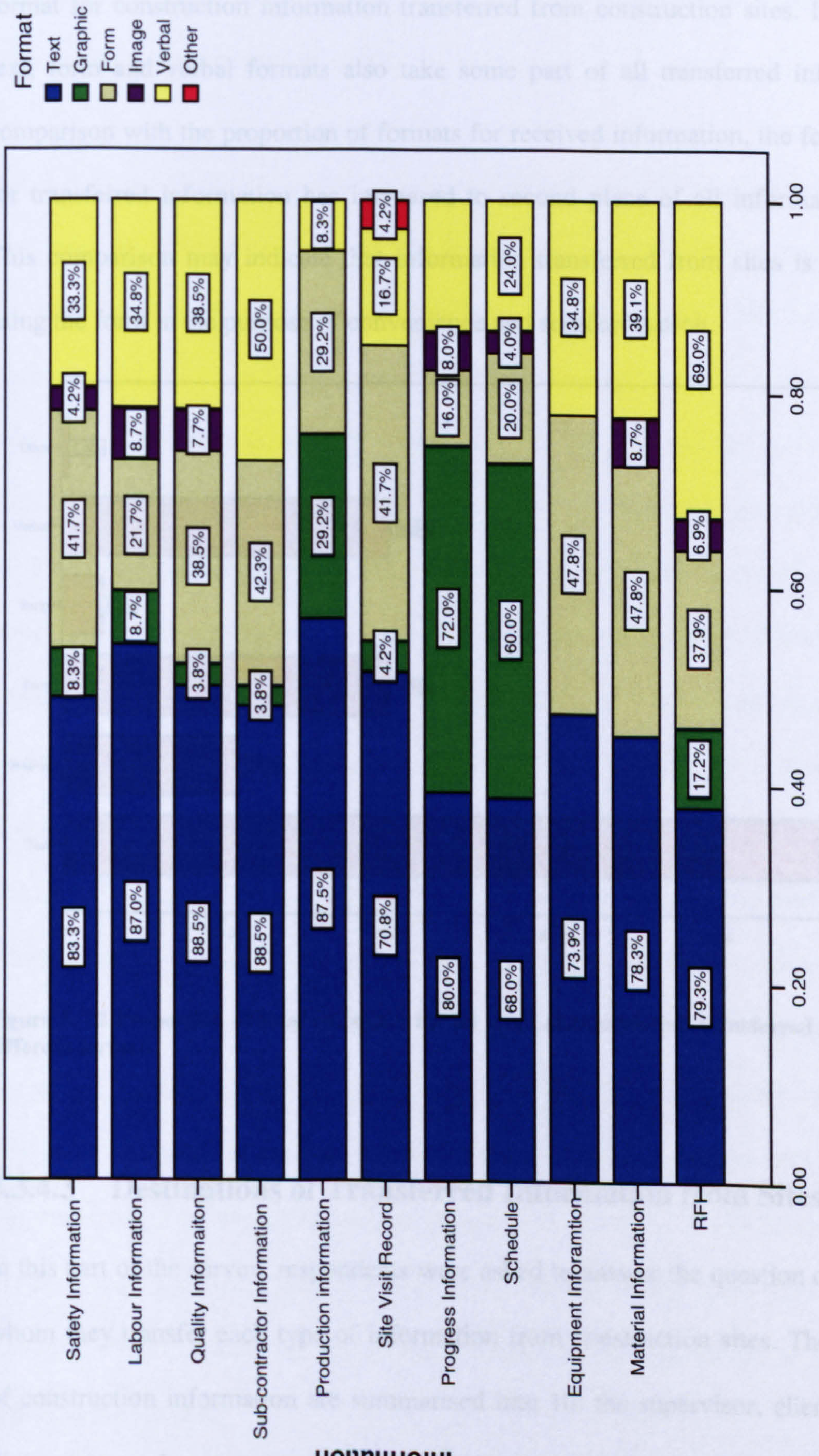


Figure 5. 21 Proportion of respondents who transfer construction information from sites with different formats

From Figure 5.22, the findings reveal that the format of text is the major information format for construction information transferred from construction sites. In addition to text, form and verbal formats also take some part of all transferred information. In comparison with the proportion of formats for received information, the format of form for transferred information has increased to second place of all information formats. This comparison may indicate that information transferred from sites is presented by using the form in the purpose of convenience and standardisation.

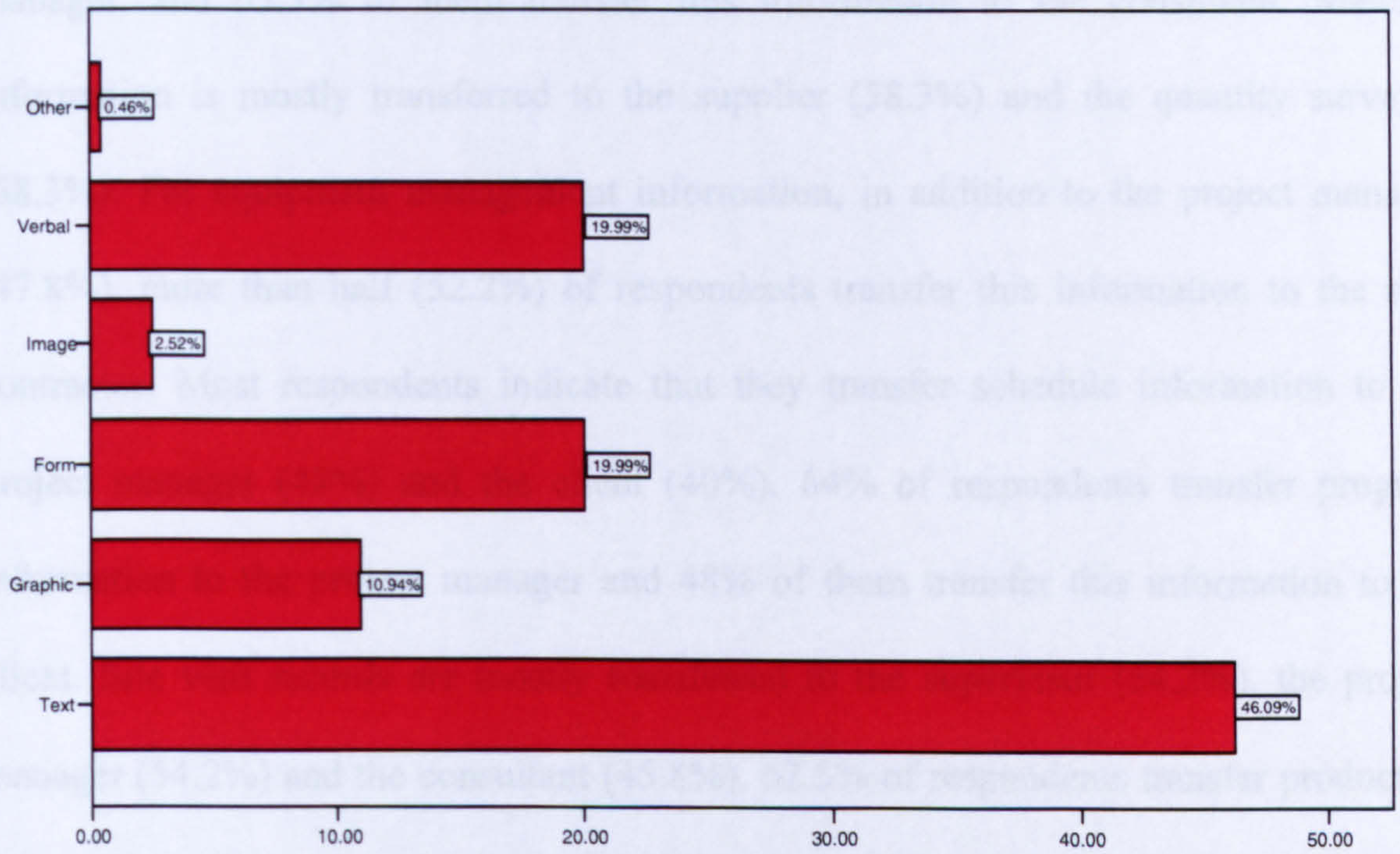


Figure 5. 22 Proportion of total responses for all types of information transferred from sites with different formats

5.3.4.3 Destinations of Transferred Information from Sites

In this part of the survey, respondents were asked to answer the question of where or to whom they transfer each type of information from construction sites. The destinations of construction information are summarised into 10: the supervisor, client, consultant, design team, sub-contractor, engineer, supplier, project manager, quantity surveyor and other. Construction information is grouped into 11 categories to ensure respondents can point out the format for each information category. This question is a multi-option question where respondents can select more than one for each type of information. All collected data was analysed by SPSS.

Figure 5.23 shows the proportion of respondents who transfer construction information from sites to different destinations. From the analysis, 72.4% of respondents indicate that they transfer RFI (Request For Information) to the design team and the project manager, and 65.5% of them transfer this information to the consultant. Material information is mostly transferred to the supplier (58.3%) and the quantity surveyor (58.3%). For equipment management information, in addition to the project manager (47.8%), more than half (52.2%) of respondents transfer this information to the sub-contractor. Most respondents indicate that they transfer schedule information to the project manager (48%) and the client (40%). 64% of respondents transfer progress information to the project manager and 48% of them transfer this information to the client. Site visit records are mostly transferred to the supervisor (54.2%), the project manager (54.2%) and the consultant (45.8%). 62.5% of respondents transfer production information to the supervisor and 54.2% of them transfer this information to the consultant. For sub-contractor information, most respondents (70.4%) transfer them to the project manager and half of them (55.6%) transfer this information to the supervisor. Quality information is mostly transferred to the project manager (53.8%), and the supervisor (42.3%). More than half of respondents (52.2%) transfer labour information to the project manager, and 47.8% of them transfer to the supervisor and quantity surveyor. Finally, 58.3% of respondents transfer safety information to the supervisor and project manager.

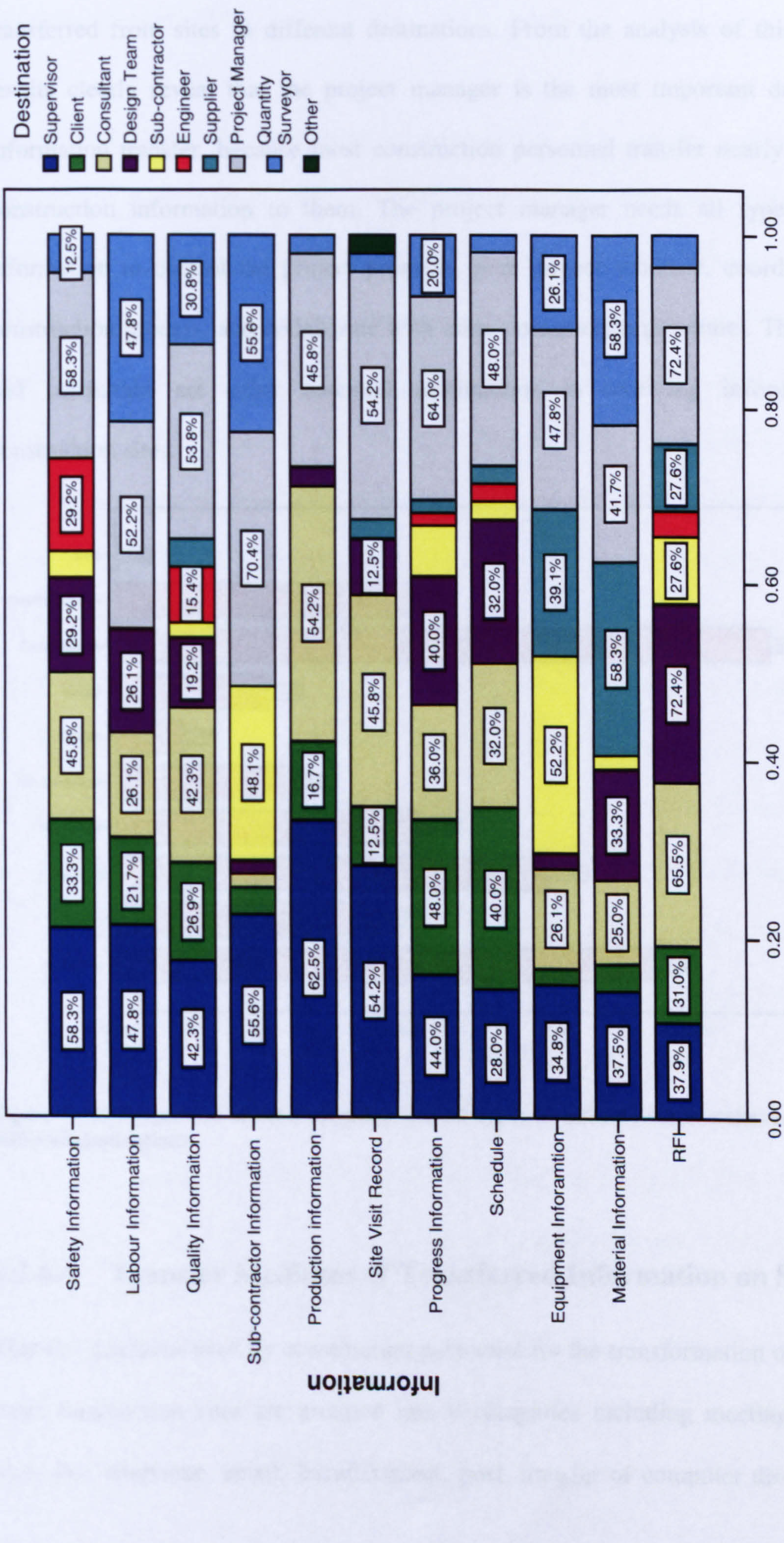


Figure 5. 23 Proportion of respondents who transfer construction information from sites to different destination

Figure 5.24 shows the proportion of total responses for all types of information transferred from sites to different destinations. From the analysis of this figure, the results clearly reveal that the project manager is the most important destination of information transfer, because most construction personnel transfer nearly all types of construction information to them. The project manager needs all types of project information to control the project progress, plan project schedule, coordinate on-site construction process, and collaborate with other construction personnel. The supervisor and consultant are other essential destinations in receiving information from construction sites.

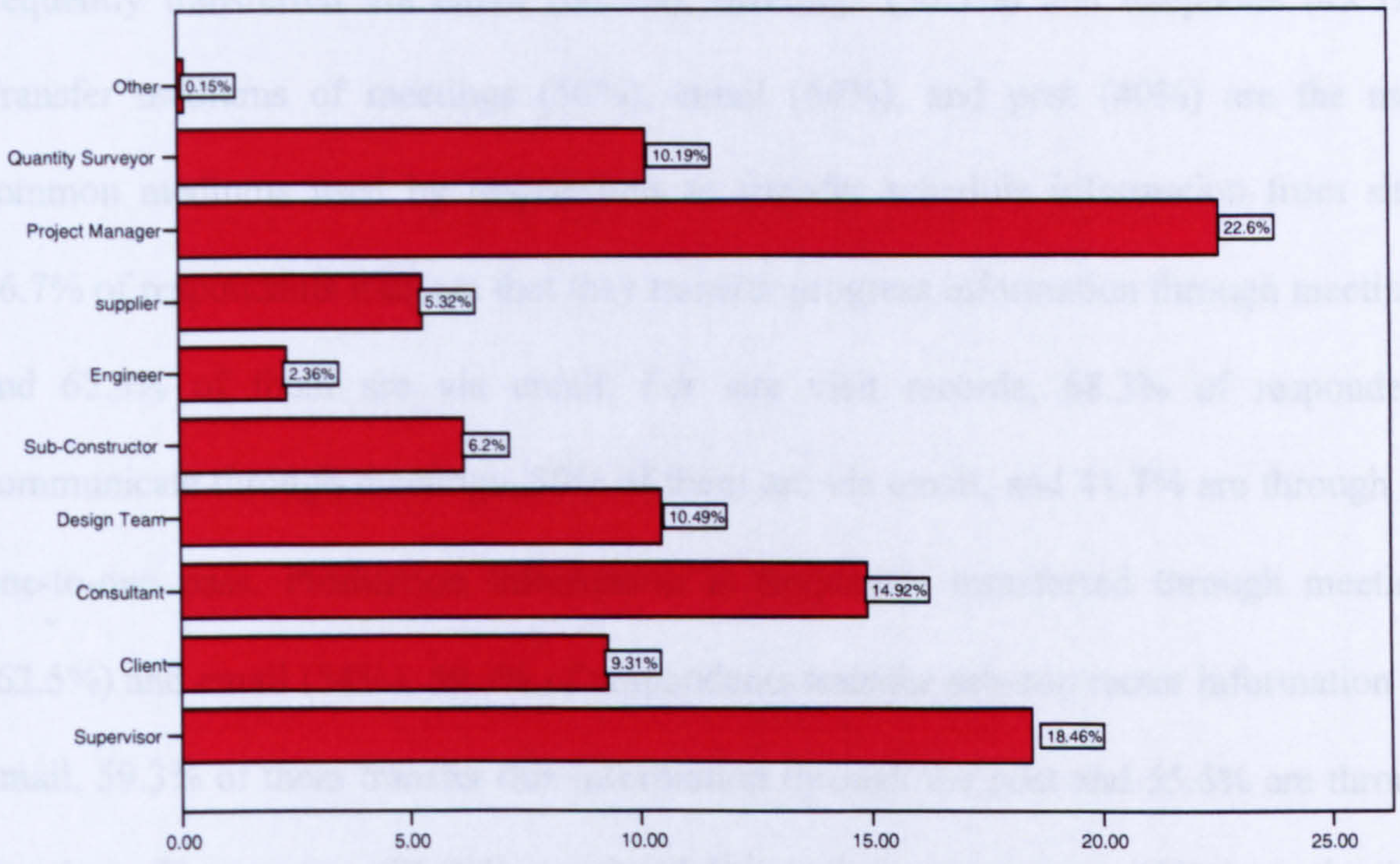


Figure 5. 24 Proportion of total responses for all types of information transferred from sites to different destinations

5.3.4.4 Transfer Mediums of Transferred Information on Sites

Transfer mediums used by construction personnel for the transformation of information from construction sites are grouped into 9 categories including meetings, one-to-ton pass, fax, telephone, email, Intra/Extranet, post, transfer of computer discs, and other.

This question is also a multi-option question. The proportion of transfer mediums was calculated by using SPSS.

Figure 5.25 shows the proportion of respondents who transfer information from construction sites through different transfer mediums. From this figure, 75.9% of respondents indicate that they transfer RFI (Request For Information) via email and 69% of them transfer RFI through meetings and telephone. For material information, most respondents (66.7%) transfer it via email, 62.5% of them transfer it through meetings, and 50% of them are through telephone calls. Equipment information is frequently transferred via email (60.9%), meetings (56.5%) and telephone (43.5%). Transfer mediums of meetings (56%), email (64%), and post (40%) are the most common mediums used by respondents to transfer schedule information from sites. 66.7% of respondents indicate that they transfer progress information through meetings, and 62.5% of them are via email. For site visit records, 68.3% of respondents communicate through meetings, 50% of them are via email, and 41.7% are through the one-to-one pass. Production information is frequently transferred through meetings (62.5%) and email (54%). 59.3% of respondents transfer sub-contractor information via email, 59.3% of them transfer this information through the post and 55.6% are through meetings. The meeting (76.9%), email (61.5%) and one-to-one pass (50%) are the three common transfer methods through which respondents transfer quality information. Labour information is commonly transferred through meetings (69.6%), email (65.2%) and telephone (43.5%). 79.2% of respondents transfer safety information through meetings and 62.5% of them transfer it via email.

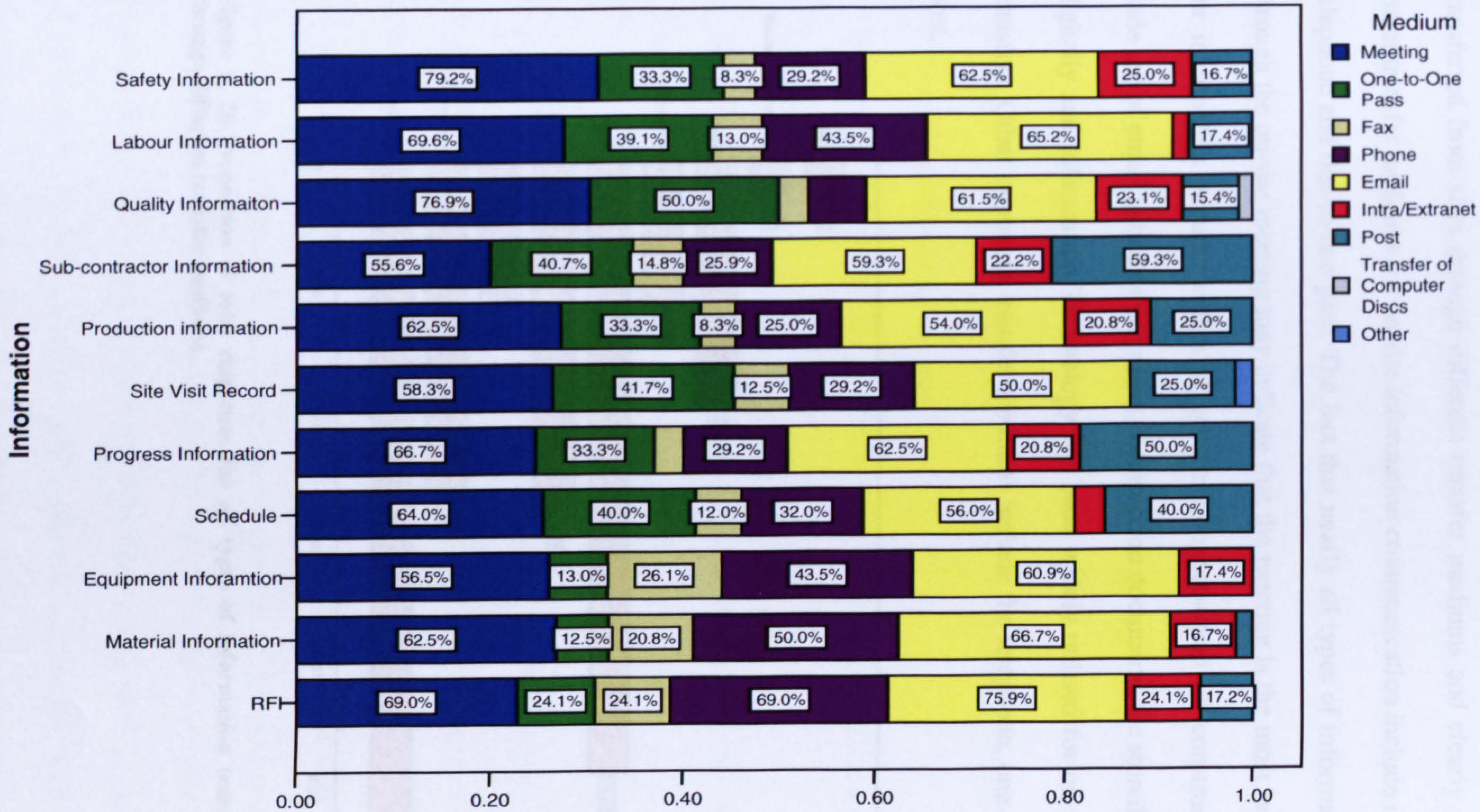


Figure 5. 25 Proportion of respondents who transferred information from sites through different transfer mediums

Figure 5.26 shows the proportion of total responses for all types of information transferred from sites through different transfer mediums and clearly reveals that the major transfer mediums for on-site information communication include meetings, email, telephone and one-to-one pass. The fact that nearly all types of information transferred through the on-site meeting may indicate that the meeting is the most important method for information communication of construction personnel on construction sites. The wide use of email indicates that many construction documents are stored and transferred digitally and Information Technology has been widely utilised for on-site information transfers. Other important transfer mediums include the telephone, one-to-one pass and post.

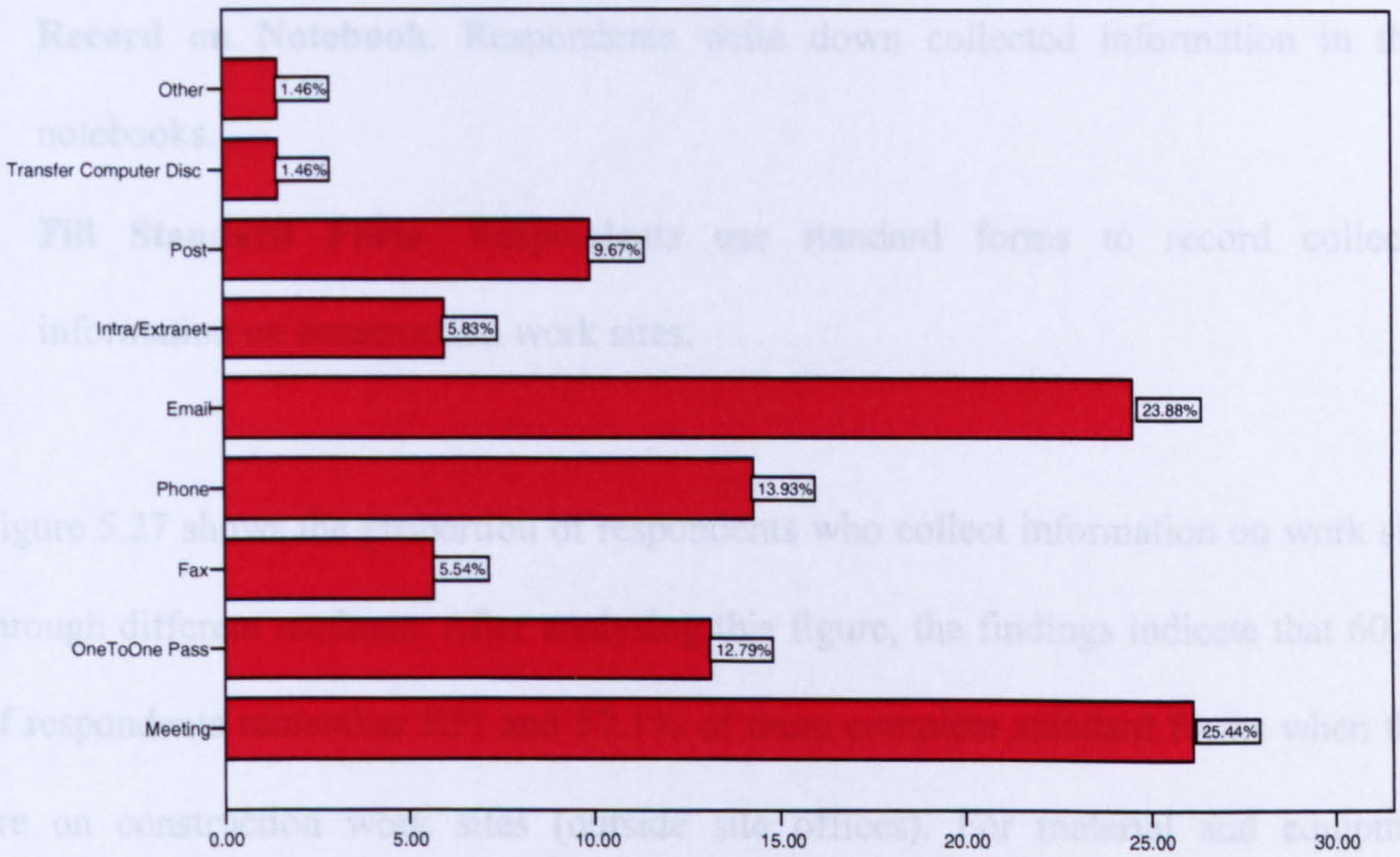


Figure 5. 26 Proportion of total responses for all types of information transferred from sites through different transfer mediums

5.3.4.5 Information Collection on Work Sites

In this part of the survey, respondents were asked to answer how they collected the necessary information on construction work sites (outside site offices). Construction information is grouped into 11 categories, corresponding to the above questions. The methods that respondents use to collect information on work sites include the following:

- **Use Mobile Devices.** Respondents use mobile devices, such as PDAs, Palm PCs, pocket PCs and wearable computers, to collect and capture construction information on work sites.
- **Memory.** Respondents remember collected information when they need to capture construction information on work sites.
- **Record on Notebook.** Respondents write down collected information in their notebooks.
- **Fill Standard Form.** Respondents use standard forms to record collected information on construction work sites.

Figure 5.27 shows the proportion of respondents who collect information on work sites through different methods. After analysing this figure, the findings indicate that 60.7% of respondents remember RFI and 57.1% of them complete standard forms when they are on construction work sites (outside site offices). For material and equipment information, more than half of respondents remember related information (54.2% and 54.2%) or complete standard forms (54.2% and 50%). 64% of respondents complete standard forms for collected schedule information and 48% of them record this information in notebooks. For collected progress information, 64% of respondents complete standard forms and 44% of them record this information in notebooks. 56.6% of respondents keep relevant information in notebooks when they visit construction work sites. Production information is normally collected and kept through completing standard forms (70.8%). Remembering (56%), recording in notebook (48%) and completing standard forms (44%) are the most used methods for respondents to collect and keep sub-contractor information. Completing standard forms (65.4%) and recording in notebooks (46.2%) are mostly used for collecting quality information. 69.6% of respondents complete the standard forms for the collection of labour information. Safety information is normally collected and maintained in notebooks (62.5%) on construction work sites.

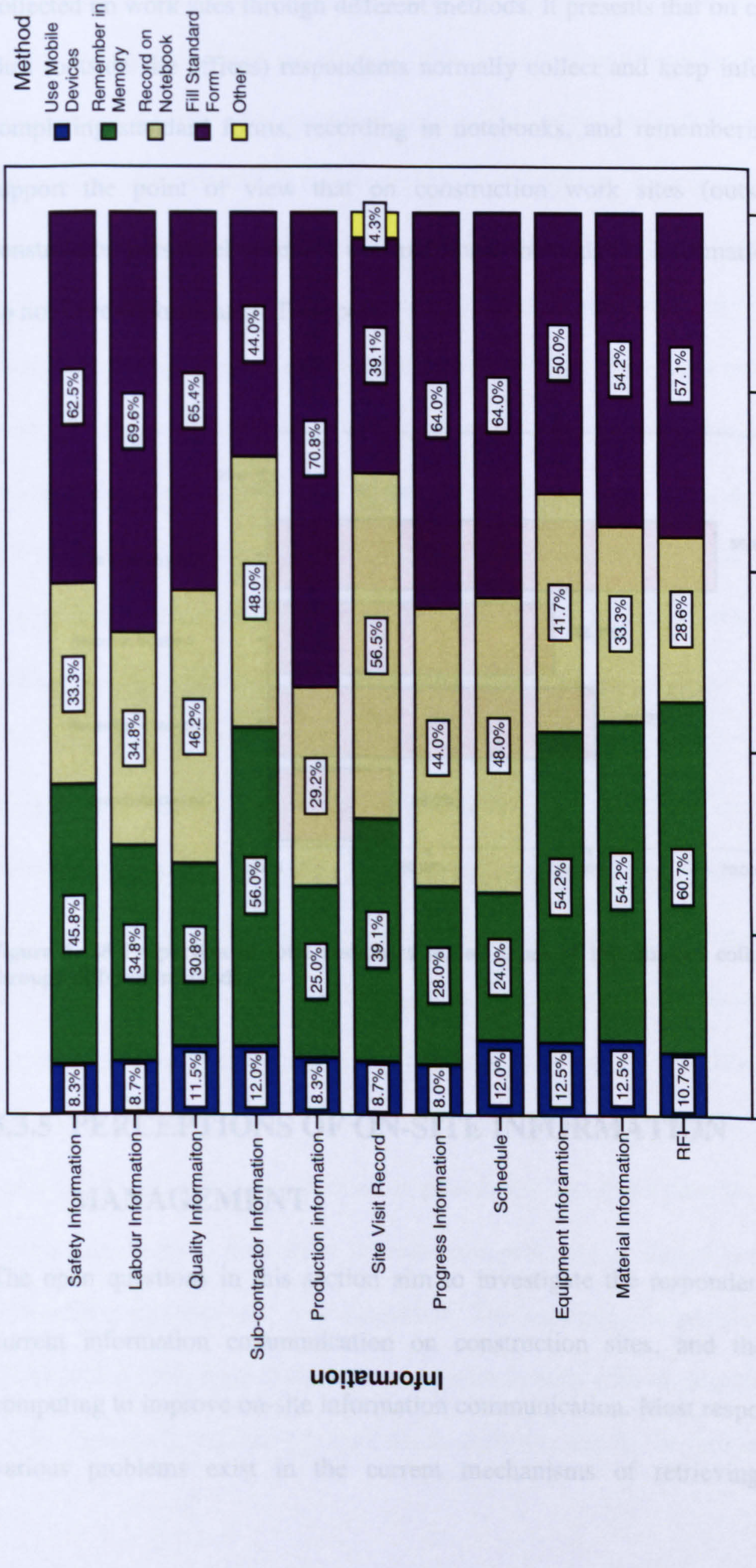


Figure 5. 27 Proportion of respondents who collected information on work sites with different methods

Figure 5.28 shows the proportion of total responses for all types of information collected on work sites through different methods. It presents that on construction work sites (outside site offices) respondents normally collect and keep information through completing standard forms, recording in notebooks, and remembering. The findings support the point of view that on construction work sites (outside site offices) construction personnel normally use traditional methods for information collection and do not have sophisticated IT support.

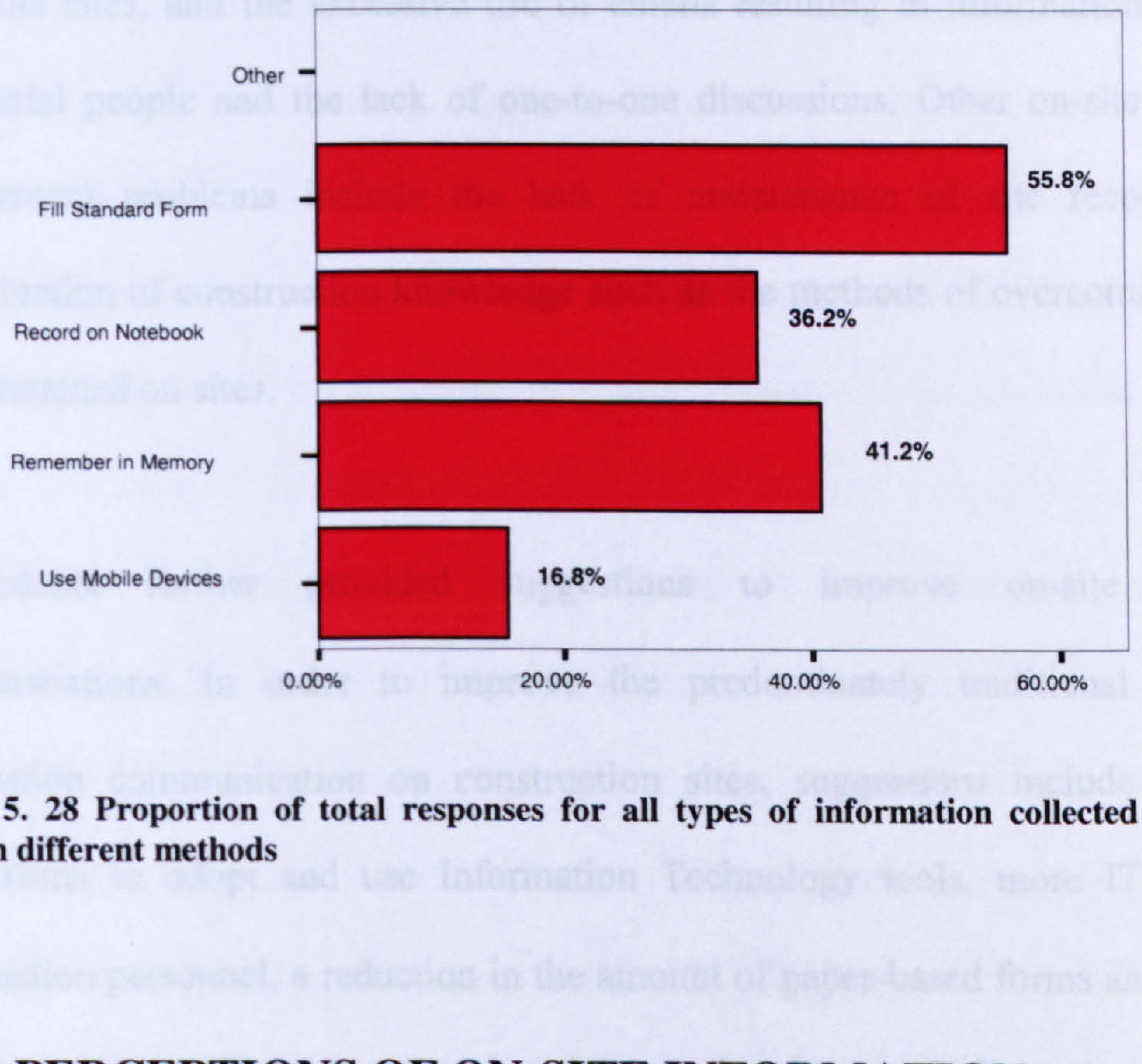


Figure 5. 28 Proportion of total responses for all types of information collected on work sites through different methods

5.3.5 PERCEPTIONS OF ON-SITE INFORMATION MANAGEMENT

The open questions in this section aim to investigate the respondents' perception of current information communication on construction sites, and the use of mobile computing to improve on-site information communication. Most respondents admit that various problems exist in the current mechanisms of retrieving, collecting and transferring information on construction sites. Because most small projects are still predominately traditional, some problems are associated with the traditional ways of retrieving and transferring information. These kinds of problems include the inefficient retrieval and transfer of paper-based information mediums, and the constant delay of information communication between project participants. Additionally, many existing problems are related to the application of Information Technology tools. These kinds of problems include the restriction of network bandwidth leading to the slow speed of Intranet/Extranet and other collaboration tools, the lack of network connection methods to remote sites, and the excessive use of emails resulting in information overload to managerial people and the lack of one-to-one discussions. Other on-site information management problems include the lack of maintenance of site records and the dissemination of construction knowledge such as the methods of overcoming problems that is retained on sites.

Respondents further provided suggestions to improve on-site information communications. In order to improve the predominately traditional methods of information communication on construction sites, suggestions include encouraging small firms to adopt and use Information Technology tools, more IT training for construction personnel, a reduction in the amount of paper-based forms and documents, and illustrative projects that examine the benefits that result from the use of IT on construction sites. For construction organisations that have already used Information Technology tools in their daily business proceedings, the design and management of information systems are very important. For example, Intranet/Extranet and other collaboration tools need to be sized to be able to cope with increased electronic traffic. Intranet/Extranet and related application software should be properly designed and managed. Excessive use of emails should be reduced through the encouragement of one-to-one discussions and group meetings.

Mobile computing as an emerging new technology has been recognised by most respondents as the potential tool to provide benefits to on-site information management. This is because construction information can be delivered more quickly to construction work sites and users can have a permanent record of information sent. The use of mobile computing allows users to search and retrieve information more accurately, and to 'carry' more information on construction work sites with the capability of instantly accessing 'carried' information. Remote access to electronic document management systems avoids carrying vast amounts of hard copy on work sites. The use of mobile computing on work sites can increase the collaborative and cooperative capabilities between on-site construction personnel. However, some respondents mention that the benefits can only be obtained on sites where IT support is constantly available, IT products are more dependable, and the limitations of mobile computing are well addressed. Areas that can benefit most from the use of mobile computing are suggested by respondents, such as communication on work sites rather than communication in site offices, the transmittal of information across all involved sites in a project, the senior and middle managerial personnel, technical information management, especially surveys and instrumentation data, and the communication of other management and control information including quality control information, subcontractor information, deliveries, and safety records.

In addition to the suggested benefits, respondents are also concerned about the potential barriers to the implementation of mobile computing on construction sites. Mobile computing technologies should be evaluated first in demonstration projects before being widely adopted by construction firms. Mobile computing should only be adopted if support and training are given from the top to the bottom to create a competent team and if mobile devices are of sufficient quality and standard. Limitations in mobile computing, such as the limit of local computational resources that they are more vulnerable to loss or damage, the variety of connectional performance and reliability and the concern of power consumption, should be addressed and improved.

5.3.6 SUMMARY OF KEY FINDINGS

The conducted survey aimed to explore the mechanism of information communication on construction sites, and looked at the following aspects: information needs of on-site construction personnel, the nature of information, sources and destinations of information, mediums of information communication, and approaches of information access and collection on work sites. The survey was carried out via the Internet, first as a pilot survey and then a final survey. All collected data was analysed by statistical software SPSS.

5.3.6.1 Construction Personnel and Construction Sites

The survey targeted managerial professionals who had sufficient working experience in the construction industry. The sample frame resulted from a random selection of the statistical sample containing 220 construction professionals who had sound construction knowledge and experience on construction sites. Survey respondents consisted of managing directors, proposal managers, quality managers, quantity surveyors, and site managers. The working experience of respondents surveyed varied from less than 1 year to more than 20 years. 55% of respondents had worked in the construction industry for more than 20 years. Respondents were construction domain experts rather than IT domain experts although they had sufficient computer and network related knowledge to use Information Technology to assist in their work.

In this survey, respondents were asked to describe the last project in which they had been involved. The description of last projects looked at the project type, value, duration, and construction site type. Projects surveyed covered nearly all types of construction projects and were mostly medium-scale and large-scale projects. These findings were indicated by the project duration (mainly 1 and 2 years), investment (86.2% over 1 million pounds) and project construction sites (68.9% with medium or large size construction sites).

Construction personnel normally need to visit construction work sites, including all areas outside the site offices, during the duration of project construction. The major workplaces of senior executives and functional managers were normally inside site offices, in which they perform and complete most of their work and responsibilities, with the occasional visit to work sites. Moreover, on-site managers and engineers had to spend most of their time on work sites in order to carry out their construction activities.

The major type of IT used on construction sites was laptop computers with connection to networks; the use of pocket PCs and pocket PC phones was not normally adopted on construction sites. Because laptop computers can only be used inside site offices, these findings supported the point of view that IT support including computers and networks had been extended to construction site offices and managerial personnel were normally equipped with fixed computers, but actually on site little IT support is available. Computer and software application had been extensively used to manage construction business processes on construction sites. The wide range of construction business processes supported by Information Technology tools suggested that there were plenty of efficient and helpful software tools available for managerial personnel to assist them with the management of business processes.

5.3.6.2 Retrieved and Transferred Information on Sites

Construction sites are information intensive environments where construction personnel not only receive all types of information from other sources but also transfer information to various destinations. Drawings were the most important information on sites, which was demonstrated by the fact that nearly all respondents received drawings on construction sites. Other main types of information received on sites included specifications, contract information, progress information and sub-contract information. In contrast, Request For Information (RFI) was the major type of information that respondents transferred from construction sites. The intensive information environment of construction sites and the information requirements of construction personnel emphasised the importance of on-site IT support, including computer hardware and software.

Information needs of construction personnel were linked to their managerial responsibilities. Senior executives including the managing director, project director and project manager, needed all types of information to plan, organise, and control the current progress of a construction project. Different types of functional managers needed specific information that related to their functional duties to support their work.

5.3.6.3 On-site Information Format

The major formats of construction drawings were graphic and image, which required vast amount of papers to represent construction drawings. The most common format of other on-site information was text. Excluding drawings, other types of construction information that are received on sites or transferred from sites were mostly presented and described by text. In addition to text, progress information, design clarification and construction methods were presented with additional graphics. The format of form that required standard data input was not widely used to present received on-site information, but was widely used to transfer information from sites for the purpose of convenience and standardisation. Construction information transferred from sites presented with 'form' included material information, equipment information, schedule, progress information, site visit record, and safety information. The format of verbal communication implied that construction personnel had conversations with other people in order to obtain or provide required information. Verbal communication was one of the important supplemental methods for construction personnel to retrieve or transfer information on construction sites.

The graphic format of drawings and the extensive need of drawings on construction sites indicated the contradiction between the requirements of displaying large size graphics and the limitation of the small size screen of mobile devices. In order to resolve this contradiction, the use of mobile computing to retrieve and present construction drawings should consider the following three perspectives based on the concept of mobile computing. First, the selection of mobile devices should consider the screen size when the main use of selected mobile devices is to display construction drawings. Second, the design of mobile application to display construction drawings should consider the question of what size drawings can be presented clearly and conveniently on the small size screen of mobile devices. Some software functions are necessary, such as zoom in, zoom out and scroll. Finally, the selection of wireless networks should consider those networks with big bandwidth in order to overcome the delay of transferring big files.

The variety of information formats require that mobile computers should have the ability to process and transfer different information formats including graphic, text, verbal, and image. Therefore, mobile computers are required to have a diversity of information input and output methods. Some examples of input or output equipment for mobile computers include the phone keypad, portable keyboards, handwriting recognition, speaker and screen. The various formats of construction information impact on the HCI (Human Computer Interaction) design of mobile computers; in contrast, the HCI design of mobile computers can restrict the input and display of construction information.

5.3.6.4 Sources and Destinations of On-site Information Transfer

The project manager was the most important source of transferring information to other on-site construction personnel. The sub-contractor was another main source for transferring information to construction sites, because sub-contractors needed to transfer their construction processes, construction activities, progress and other related information to other participants involved in the project for the purpose of collaboration. The design team was the major element that took responsibility for providing technical and engineering related information, such as drawings, contract, design clarification, construction and engineering method, and specification. Information transferred from the supervisor included progress, safety, labour and quality information. The client and consultant were the main people who kept contract information. Additionally, the project manager was the most important destination when on-site construction personnel transferred nearly all types of information. The project manager required all project-related information to control project progress, plan project schedules, coordinate on-site construction processes, and collaborate with other construction personnel.

The findings indicated that the design of mobile computing systems should consider the information flow in terms of who needs what information from where. Because a construction project involves many sub-constructors who are another major destination that can provide information and are normally outside the boundary of the information systems of the main contractor firm, the design of mobile computing systems should consider how sub-constructors can be integrated into the main information systems during the whole project life-cycle in order to improve communications between the main contractor and sub-contractors. These suggested that mobile computing can provide the potential benefits of improved and integrated collaboration between project participants. The source and destination of information required by on-site construction personnel can affect the selection of wireless networks for the design of mobile computing systems. If the required information is digitally stored in computer systems, on-site personnel can use mobile computers with a connection to the infrastructure of information systems through wireless networks. If the required information were kept by other personnel, users can simply make a telephone call through the mobile phone function that is normally the major function of a Pocket PC phone.

5.3.6.5 On-site Information Transfer Mediums

The major information transfer mediums that were used by respondents to retrieve and transfer information on construction sites included meetings, email and post. The fact that nearly all types of information were communicated in on-site meetings indicated that on construction sites the on-site meeting was the most important method for construction personnel to communicate, exchange, and coordinate information. The fact that the exchange of information via email had become a more common practice revealed that many construction documents were stored and transferred digitally and IT tools including computers and networks had been widely utilised for the management of information on construction sites. As a traditional method, the post was still an important information transfer method for construction personnel. Compared with email, the Intra/Extranet was not widely utilised by respondents to retrieve or transfer information.

5.3.6.6 Construction Work Sites Information Retrieval and Collection

On construction work sites (outside site offices), respondents normally retrieved information by making telephone calls, retrieving from memory and reviewing documents by hand. The collection of information on construction work sites can be done through the methods of completing standard forms, recording in notebooks, and remembering information. The findings supported the point of view that on construction work sites (outside site offices) construction personnel generally used traditional methods for information communication and did not have sophisticated IT support. Compared with the IT support in site offices, there was a need to integrate information communication between site offices and work sites in order to make construction work sites more digital and informatization, and therefore, streamline the information communication and business process.

5.3.6.7 Perceptions of On-site Information Management

Most respondents admitted that there were various problems in the current mechanisms of retrieving, collecting and transferring information on construction sites. These problems resulted from the predominately traditional methods of information communication and the problems of applying Information Technology tools. Respondents further provided suggestions for the improvement of on-site information communication, such as the improvement of traditional ways of information communication, the encouragement of the use of IT tools, more IT training for construction personnel, demonstration projects, and the appropriate design and management of information systems in organisations.

Mobile computing has been recognised by most respondents as a potential tool to provide benefits to on-site information management. Benefits include the quick delivery of information to work sites, more accurate search and retrieval of information, instant access to 'carried' information on work sites, remote access to electronic document management systems, and increased collaborative and cooperative capabilities between on-site construction personnel. However, some respondents mentioned that the benefits can only be obtained on sites where IT support was constantly available, IT products were more dependable, and the limitations of mobile computing were well addressed.

Besides the benefits, respondents were also concerned with the potential barriers to the use of mobile computing on construction sites. The potential barriers included the lack of evaluation of mobile computing technologies on construction sites, the lack of support and training for construction personnel, the uncertainty of the quality and standard of mobile computing technologies, and the inherent limitations of the technology itself.

5.4 SUMMARY

This chapter highlighted how the findings were drawn from case studies and the survey and provided an overview of the findings resulting from this empirical research. The framework for using mobile computing in on-site information management that uses the findings from the literature review, case studies and the survey is presented and discussed in the next chapter.

CHAPTER 6

A FRAMEWORK FOR USING MOBILE COMPUTING FOR CONSTRUCTION SITE INFORMATION MANAGEMENT

6.1 INTRODUCTION

One of the objectives of this research project is to explore how mobile computing can be used on construction sites by construction personnel to manage on-site information. This chapter describes the framework through the identification of key factors and the clarification of interrelationships between these factors. Firstly, the framework identifies six primary factors: 'mobile computer', 'wireless network', 'mobile application', 'construction site', 'user' and 'construction information'. Then, each primary factor is further divided into sub-factors that reflect the detailed features of the relevant primary factor. Finally, the framework is broken down into different sub-frameworks, each of which presents the specific relationships of the sub-factors between two primary factors. The intention is to use the developed framework to provide guidance in the effective selection of Mobile Computing strategies for on-site information management.

6.2 THE DEVELOPMENT OF THE FRAMEWORK

The conceptual framework discussed in Section 3.10.1 has provided a possible integration between the concept of construction information management and mobile computing, and discussed the implementation of mobile computing at each level of construction information management. At the information retrieval and provision level, construction personnel use mobile computers to retrieve and transfer information for their information requirements. At the level of mobile computing systems, the integration of mobile computers, wireless networks and mobile applications is the key system for mobile information processing and wireless communication. At the organisational level, the construction company determines the tasks that mobile computing systems need to perform and re-engineers the construction processes to maximise the benefits of using mobile computing technologies.

This conceptual framework provided general guidance for the development of a final framework from two aspects. First, the identification of primary factors and their sub-factors in the final framework should concern all three levels of using mobile computing for construction information management. The use of mobile computing at each level has different requirements and construction information management at different levels has a different impact on the implementation of mobile computing. Second, the interrelationships between factors in the final framework should not only concern the links between factors at the same information management level, but also the links between factors at different levels. This is because the use of mobile computing for information management at each level in the conceptual framework is not isolated but coherently linked with adjacent levels.

Findings from the literature review, case studies and the survey are used as evidence to set up the final framework from the two main aspects of the identification of sub-factors and the exploration of their interrelationships. On one hand, the findings identify the sub-factors for each primary factor. The analysis and generalisation of features for commercially available mobile computing products provides the identification of sub-factors for the three primary factors of 'mobile computer', 'wireless network', and 'mobile application', see Sections 3.4, 3.5 and 3.6. The visits to construction sites and interviews with construction personnel present the general environment and circumstances for the 'construction site' that is another primary factor in the final framework (Section 5.3). The survey coupled with case studies identifies sub-factors for the two primary factors: 'user' and 'construction information' (Sections 2.4, 5.3, 5.4.2, 5.4.3 and 5.4.4). These sub-factors include 'user's role', 'user's mobility', 'information type', 'information format', 'file size', and 'information flow'. On the other hand, the findings contribute to the exploration of links between identified factors. The conceptual framework has shown the interaction between mobile users and mobile computers at the information retrieval and provision level, which indicates the issue of Human Computer Interaction (HCI) that has been involved in the final framework (Section 3.10.1). The information requirements of different construction personnel, which were investigated in the case studies and the survey, provide evidence of what types of construction information mobile computing systems have to deal with and the consideration of how mobile computing can meet user's information needs, see Sections 5.2, 5.3.3.1, 5.3.3.5, 5.3.4.2 and 5.3.4.5. These are involved in the framework as the links between the user and mobile computing. The nature of on-site information investigated in the survey raises the question of how mobile computers coupled with mobile applications can deal with the input/output of construction information and whether wireless networks have the capability to transfer them at a satisfactory speed (Sections 5.3.3.2 and 5.3.4.2). These are involved in the final framework as relationships between construction information and mobile computing. The mechanism of construction site information management investigates the information sources from which users retrieve construction information and the information destinations to which users transfer construction information (Sections 5.3.3.3 and 5.3.4.3). This requires that mobile computing systems should have the ability of transferring information between users and information sources or destinations. The mechanism also requires the coverage of wireless networks to meet the distance between the user and information sources or destinations. The directions of information flow require mobile computers and mobile applications to have connection methods and data transfer methods for data communication.

6.3 TOP-LEVEL FRAMEWORK

The top-level framework, shown in Figure 6.1, consists of six primary factors, three independent factors and three dependent factors. The three dependent factors, 'mobile computer', 'wireless network' and 'mobile application', are the fundamental components of the concept of mobile computing. The three independent factors, 'user', 'construction information' and 'construction site', are elements that determine the use of mobile computing in a particular context. The independent factors explain the specific construction environment in which mobile computing will be implemented to manage information, and determine the design of mobile computing systems. Therefore, the three components of mobile computing are the dependent factors where the consideration of implementation should depend on the various construction circumstances defined by the independent factors.

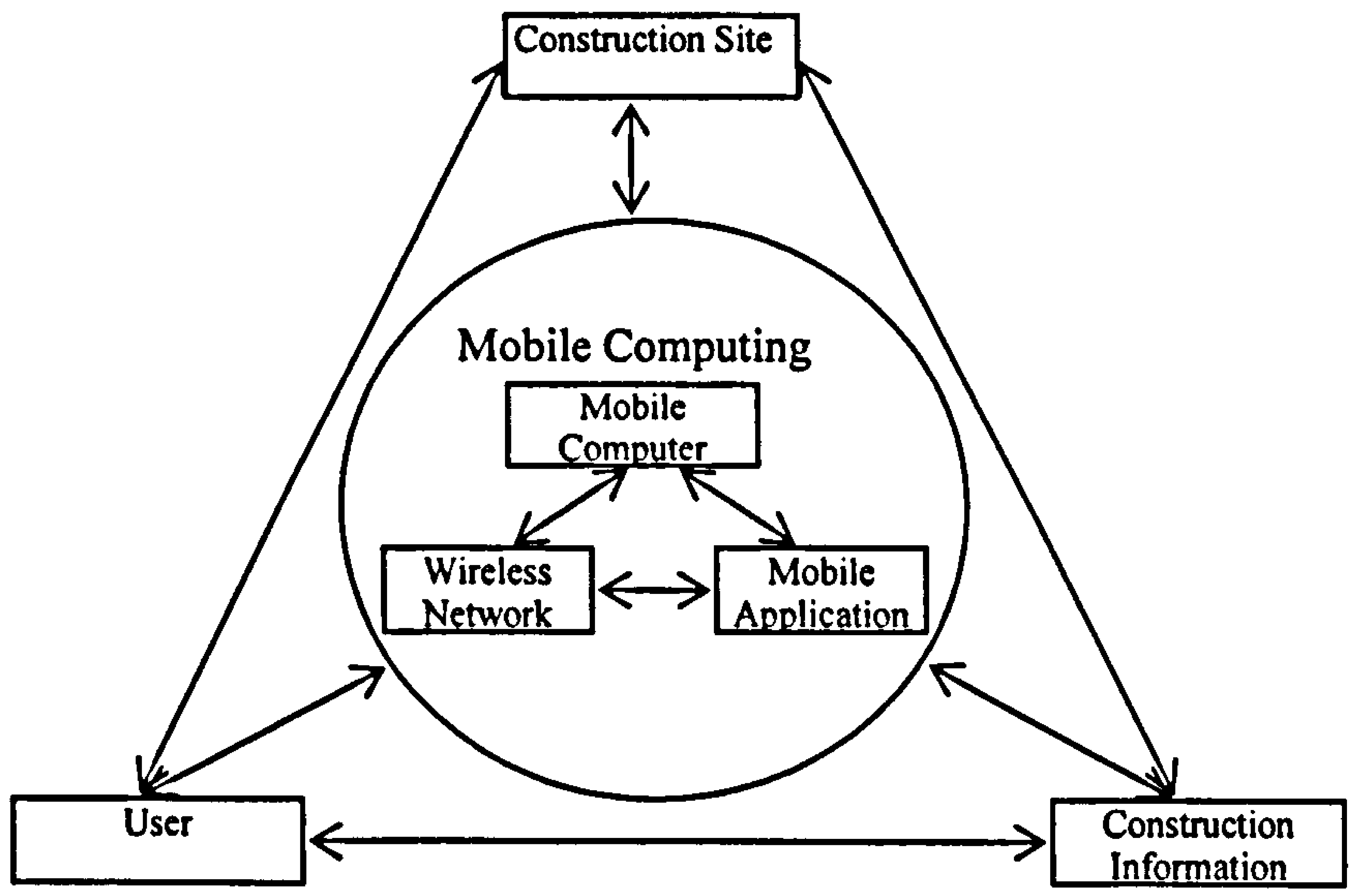


Figure 6. 1 The framework of using mobile computing in on-site information

The six primary factors in this framework are defined and explained as follows:

- **Mobile Computer.** As one of the three dependent factors, the mobile computer can be used indoors and outdoors by users while in motion. Typical mobile computers include tablet PCs, all kinds of pocket computers, palmtops, wearable computers, and they typically have lots of accessory devices such as sensors, digital pens, bar-coding devices and laser distance meters. However, they exclude conventional notebooks because the general use of notebooks is fixed in offices, similar to the use of desktops. Features of the mobile computer consist of the operating system, the speed of the processor, the capability of storage, input and output features, physical features, the duration of the battery and the network connectivity. All these features will be identified as sub-factors of the primary factor 'mobile computer'. A detailed description of mobile computers can be found in Section 3.4.

- **Wireless Network.** The wireless network is another dependent factor. Wireless networks with sufficient bandwidth can support the connection and communication of mobile computers and can be accessed while mobile computers are in motion. The type of wireless network considered excludes wired networks but includes all kinds of wireless one, such as Wireless Wide Area Networks (WWAN), Wireless Local Area Networks (WLAN), Wireless Personal Area Networks (WPAN), and satellite networks. Each type of wireless network can be described by the data rate, bandwidth, frequency, geographic coverage, and specific technology features, see Section 3.5.
- **Mobile Application.** The third dependent factor is the mobile application, that is, the mobile computer software with the attributes of context-sensitivity and personalisation. This indicates that mobile applications can support mobile users' work processes and enable them to work together collaboratively and cooperatively in a mobile computing environment. They can further respond to the specific characteristics of mobile computers and wireless networks. Features of mobile applications include the function, system requirement, network connection method, and information input and output. The detailed description of mobile applications can be found in Section 3.6.
- **Construction Site.** The construction site is comprised of two main components: the construction work site and the site office. The construction work site refers to the areas of material storage spaces, actual operation places, equipment locations and other operational fields outside site offices. The construction site office is the headquarters for the store of construction information and the work place for managerial personnel such as the project manager, foremen, and engineers. The reason for dividing the construction site into two components is based on the

information flow boundary between work sites and site offices. The site office stores all types of documents, contracts, drawings and specifications. The work site is the area where actual construction activities are carried out. Construction individuals on work sites need to retrieve adequate information to sustain their construction activities and meanwhile transfer sufficient information back to managerial people for project monitoring and control. The case studies of construction sites can be found in Section 5.3.

- **User.** The user is another key independent factor in this framework. The user is the potential construction personnel who use mobile computing technologies to retrieve, process, and transfer information on construction sites. According to the definition of mobile construction workers, the independent factor 'user' is considered to have three types: fixed worker, semi-fixed worker, and mobile worker. The fixed worker normally works at site offices and uses the desktop PCs or laptops with the connection to a fixed Local Area Network or a Wireless LAN, where cabling is not appropriate. The semi-fixed worker normally uses desktops or laptops at site offices, but they have to move from place to place at construction work sites in between working periods. Their communication infrastructure can be either a fixed LAN at site offices or a wireless network providing coverage in the area of construction work sites. The mobile worker normally uses mobile computers whilst moving around construction work sites or remaining at site offices for short periods of time. Their communication infrastructure can be either a WLAN or a mobile network (radio or telephone) providing coverage in the work area. The survey conducted in the third research step investigated the profile of on-site construction personnel, see Section 5.4.2.

- **Construction Information.** Construction information in this framework refers to all the information that construction personnel receive, collect, transfer, and communicate to support their construction activities during the period of project construction. Construction information has been identified at organisational level, such as technical information, commercial information and management and control information, and at construction individual level such as requests for information, materials management, equipment management, cost management, schedule and means and methods, site records, submittals, and safety information. Features of construction information consist of the information format, file size, on-site information flow, on-site information processing, source, and transfer destination. The identification of construction information was introduced in the literature review (Section 2.4.1) and the mechanisms for on-site information communication were investigated in the survey research (Sections 5.4.3 and 5.4.4).

In this framework, there are three major interrelationships between these primary factors, which include the relationships between the three dependent factors, relationships between the three independent factors, and relationships between the independent factors and the dependent factors. The following section introduces the three major interrelationships:

- The relationships between the three dependent factors explore how mobile computers, wireless networks and mobile applications have an effect on each other. For example, a mobile computer should have certain abilities, including capability of storage, compatibility of the operating system and the operability of input and output interface, to perform the required mobile application software. A mobile computer also needs to have appropriate network interfaces for the connection of a selected wireless network. Additionally, mobile application software should have multi-methods of data transfer in order to incorporate user's selection of different wireless networks.

- The three independent factors also have influences on each other. Users on construction sites need to retrieve or transfer information to support their construction activities. On construction work sites, construction personnel need to manipulate and process information, which include the view, check, update, record, and collection of different information. Different construction individuals on sites have various information needs and information processing requirements. The size of a construction site and the construction processes conducted on site have an influence on the duration of time users stay on work sites.
- The major interrelationship between independent factors and dependent factors is that the implementation of mobile computing technologies including mobile computers, wireless networks and mobile application in a particular construction environment is determined by the three independent factors consisting of construction site, user and construction information. For example, the selection of mobile application software depends on the role of construction personnel who have various requirements for software functions. Construction information that flows to and from work sites determines the selection of mobile computers that should have enough capability to perform the necessary tasks and wireless networks that have required bandwidth to transfer this information.

In order to explore these interrelationships in greater depth, primary factors have been further divided into sub-factors and the framework is therefore broken down into different sub-frameworks, each of which presents the detailed relationship between two primary factors. The following sections will discuss the identification of sub-factors, the categorisation of commercially available products, and the interrelationships in sub-frameworks.

6.4 SUB-FACTOR IDENTIFICATION

The sub-factors of each primary factor are identified in this section. Commercially available products of mobile computing, user types and on-site information types are categorised into different groups according to the identified sub-factors.

6.4.1 SUB-FACTORS OF 'MOBILE COMPUTER'

A mobile computer is a computer device that the user can use indoors and outdoors while in motion. After an extensive review of current commercially available mobile computers (see Section 3.4), the major characteristics of mobile computers are summarised and analysed to provide the evidence for the identification of sub-factors. Each characteristic is considered to be one of the sub-factors for the primary factor 'mobile computer' in this framework. The identified sub-factors of the primary factor 'mobile computer' are explained and discussed as follows:

- **Operating System.** A mobile operating system is the platform software running on mobile computers. After being initially loaded into a mobile computer, a mobile operating system controls the components of hardware and manages all other application software running on the mobile computer. Although there are a number of mobile operating systems available, such as Palm OS, Windows CE OS, Pocket PC OS, and Handheld PC, current mobile computers are dominated by three major mobile operating systems: Palm OS, Windows Mobile and Windows XP Tablet PC

Edition. Palm OS and Windows Mobile normally run on pocket PCs, palmtops, pocket PC phones and PDAs, and Windows XP Tablet PC Edition is only used on Tablet computers.

- **Processor Speed.** Processor speed is one of the important indexes to evaluate the performance of a mobile computer. The higher the processor speed, the quicker computer actions are processed and the more software the computer can run. Most mobile operating systems and mobile application software require a minimum processor speed. Generally, Tablet computers have similar processor speeds to desktop or laptop computers, where the speed is from 1.2 GHz to 3 GHz. In contrast, Pocket PCs such as PDAs and palmtops have far lower processor speeds from 200 MHz to 416 MHz.
- **Storage Capacity.** Mobile computers have a storage capacity to store data for the performance of application software. Typical storage devices for mobile computers include memory, hard disks, CD/DVD disks, and other expansion methods such as CompactFlash, SmartMedia Card, Secure Digital Card, Memory Stick, and USB Flash Drive. Tablet computers have much more storage capacity and storage methods than Pocket PCs, which usually use limit methods to expand their storage capacity.
- **Data Input.** Data input refers to the methods that users can use to input various data formats into mobile computers. The keyboard and mouse are the main input devices used to input data into desktop or laptop computers. The specific characteristics of mobile computers distinguish their main input methods from the traditional ways of desktop computers. Data input methods of mobile computers include the following methods: phone keypad, navigation button, QWERTY keyboard, pen-stylus and touch-screen, handwriting recognition, touch-sensitive soft keyboards, portable

keyboards, voice recognition, voice transfer, camera for picture and video recorder, and sensors. Based on the variety of mobile device types, application purposes and application environments, mobile computers usually provide multi-input methods for users to increase the efficiency and accurateness of data input.

- **Data Output.** Data output is the way mobile computers provide information to users. There are two major elements of mobile computers for data output: the screen and speaker. The screen can display information such as text, graphic, picture and video, and the speaker can provide to the user, voice, speech, and warning sounds. The size, colours and resolution of a screen are the three major features when evaluating the display ability of a mobile computer. Bigger screen size, more colours and higher resolution can display more complex pictures and graphics. This is an important issue for mobile computers used in the construction industry because they need to display construction drawings.
- **Physical Features.** The physical features of a mobile computer refer to its size, weight, rugged shell and protective case. Rugged mobile computers with industrial – strength shell and shock-mounted hard drives have the ability to resist shock, drop and vibration. The protective case can protect mobile computers from the damaging effect of water and dust. These kinds of physical features are especially important for the use of mobile computers in such environments as construction sites.
- **Battery Duration.** Because mobile computers are normally used outside offices away from a power outlet, they should have a long battery life in order to support users' information processing activities in the periods of time on work sites. Most batteries of Tablet computers last from three to four hours and some manufacturers offer batteries with a longer life from six to eight hours, but these kinds of batteries are more costly and increase the overall weight of a Tablet computer.

- **Connection Method.** A connection to wireless networks or desktop computers is essential for a mobile computer because of the integration of mobile computers with the infrastructure of organisational information systems. The connection methods for a mobile computer include synchronisation to a desktop computer with USB, Bluetooth, and IrDA, connection to a Local Area Network, connection to a Wireless Local Area Network, connection to a Cellular phone network (Wireless Wide Area Network), and to a GPS receiver.

Based on the features identified and computing performance, mobile computers can be grouped into the following categories: Smart-phone, Pocket PC, Pocket PC Phone, and Tablet PC.

- **Smart-Phone.** A smart-phone has phone capabilities and comes with a small set of application software that can perform only limited functions. Although a smart-phone can use third-party software, the miniature keypad, small screen size and low level data processing capability limit the ability of the smart-phone to run complex software applications. Some functions that a smart-phone can perform include accessing email, keeping track of calendars and taking voice notes. Table 6.1 shows examples of the Smart-Phone category.
- **Pocket PC.** Pocket PCs, including PDAs, Palmtops, Pocket computers, have more powerful data processing capability, slightly bigger screen size, multi-input methods, and the connection to Wireless Local Area Network. Pocket PCs can run more complex software applications such as Microsoft Office Mobile, Microsoft Outlook Mobile, Word Mobile, Excel Mobile, and PowerPoint Mobile. After connecting to Wireless Local Area Networks, users can browse the Internet and send email messages. Table 6.2 contains three examples of Pocket PC.

- **Pocket PC Phone.** Compared to Pocket PCs, Pocket PC Phones have all the functions and performance that Pocket PCs have, but with the addition of wireless access to the cellular phone network (Wireless Wide Area Network). However, access to the Internet through cellular phone networks incur data charges from network providers. Table 6.3 includes some examples of Pocket PC Phone.
- **Tablet PC.** Computers powered by the Windows XP Tablet PC Edition operating system, and equipped with a sensitive screen designed to interact with a complementary pen, are called Tablet PCs. Tablet PCs are fully-functional laptop PCs, but because of their direct interaction with the screen, Tablet PCs are more flexible to use, which means that they can be used while standing up or moving around. Typical frameworks of Tablet PCs include convertible framework, slate framework and rugged framework, see Table 6.4.

		Operating System	Processor Speed	Storage Capacity	Data Input	Data Output	Physical Feature	Battery Duration	Connection Method
Smart-Phone	Cingular 2125	Windows Mobile 5.0	TI OMAP 850, 200 MHz	64MB RAM, 64MB ROM,	Phone keypad, Microphone, Camera, video recorder,	Screen Size: 2.2" TFT LCD, Screen Resolution: 320x240, Speaker,	Dimensions:4.57x1.8 1x0.69 inches, Weight: 3.74 ounces, Not rugged,	Talk time: 4 Hrs, Standby time: 6 Days, Type: Li-ion 1150 mAh	Bluetooth, Infrared, USB, Cellular phone network,
	SPV C600	Windows Mobile 5.0	Unknown	64MB persistent memory	Phone keypad, Microphone, Camera,	Screen type: QVGA, Screen Resolution: 240x320, Speaker,	Dimensions: 107.7x45.9x18.8mm, Weight: 107g, Not rugged,	Talk time: 4 hours, Standby time: 6 Days, Type: LithiumIon	Bluetooth, Infrared, USB, Cellular phone network,

Table 6. 1 Smart-phone Category

		Operating System	Processor Speed	Storage Capacity	Data Input	Data Output	Physical Feature	Battery Duration	Connection Method
Pocket PC	Pharos Traveler Gps 525	Windows Mobile 5.0	Type: SC32442X Speed: 300 MHz	64MB SDRAM, 128MB ROM,	Navigation button, Stylus, Touch Screen,	Screen type: Active Matrix LCD (TFT), Screen Resolution: 320x240, Speaker,	Dimensions: 2.4Wx4.3Lx0.7D, Weight: 150g, Not Rugged,	GPS Mode: 5 hours, Standby time: 200Hours, Type: Lithium	GPS receiver, Bluetooth, IEEE 802.11b, ActiveSync,
	HP Ipaw HX2795	Windows Mobile 5.0	Type: Intel PXA270, Speed: 624 MHz	128MB SDRAM, 128MB ROM,	Navigation button, Stylus, Touch Screen, Microphone,	Screen type: 3.5" TFT QVGA, Resolution: 640x480, Speaker,	Dimensions: 76x48x44mm Weight: 154.4g Not Rugged,	14440 mAh, Lithium,	Bluetooth, IEEE 802.11b, ActiveSync,
	PalmOne LifeDrive	Palm OS Garnet 5.4, Apple MacOS, Microsoft Windows 2000/XP	Type: Intel, Speed: 416 MHz,	64MB RAM, 16MB ROM, 4 GB HDD,	Navigation Button, Stylus, Touch Screen, Microphone,	Screen type: 3.8" TFT, Resolution: 320x480, Speaker,	Dimensions: 1.9x12.1x7.3cm Weight: 193g, Protection bag,	1660 mAh, Lithium,	Bluetooth, IEEE 802.11b, IrDA, ActiveSync,

Table 6. 2 Pocket PC Category

		Operating System	Processor Speed	Storage Capacity	Data Input	Data Output	Physical Feature	Battery Duration	Connection Method
Pocket PC Phone	T-Mobile MDA	Windows Mobile 5.0	Type: TI OMAP 850, Speed: 200MHz,	64MB RAM, 128MB ROM,	QWERTY keyboard, Stylus, Touch Screen, Microphone,	Screen type: 2.8" QVGATFT LCD, Resolution: 240x320, Speaker,	Dimensions: 4.3"Lx2.3"W, Weight: 170g Not Rugged,	Standby: 200 hrs, Talk:4.5 hours, 1250 mAh Lithium	USB, Bluetooth, IrDA, IEEE 802.11b, Cellular phone network, ActiveSync,
	Palm Treo 700w (Verizon Wireless)	Windows Mobile 5.0	Type: Intel XScale, Speed: 312MHz,	128MB (60MB user accessible)	QWERTY keyboard, Stylus, Touch Screen, Microphone,	Screen type: TFT LCD, Resolution: 240x240, speaker,	Dimensions: 2.3"Wx4.4"Hx0.9"D, Weight: 245g, Not Rugged,	Standby: 15 days, Talk:4.7 hours, Lithium,	USB, Bluetooth, IrDA, IEEE 802.11b, Cellular phone network, ActiveSync,

Table 6. 3 Pocket PC Phone Category

		Operating System	Processor Speed	Storage Capacity	Data Input	Data Output	Physical Feature	Battery Duration	Connection Method
Tablet PC	TravelMate C310 Convertible tablet PC	Microsoft Windows XP Tablet PC Edition	Type: Intel Pentium M Processor Speed: 2.0GHz	1GB DDR2 SDRAM, 100GB HD, DVD-RW,	Keyboard, Electromagnetic digitizer pen Microphone,	Screen type: 14.1" XGA TFT LCD, Resolution: 1024x768, Speaker,	Dimensions: 12.8"Wx10.7"Dx1.5" H, Weight: 2.9kg, Not rugged,	4.0 hours life, Lithium,	USB, Bluetooth, IEEE 802.11b, Ethernet LAN,
	Duo-Touch rugged Tablet PC	Microsoft Windows XP Tablet PC Edition	Type: Intel Pentium M Processor 733, Speed: 1.1GHz	1280MB DDR RAM, 40G HD,	Electromagnetic digitizer pen with sensitive screen, Microphone,	Screen type: 8.4" SVGA TFT, Resolution: 1024x768, Speaker,	Dimensions: 10.6"Lx7.2"Wx, Weight: 2.9kg, Rugged for shock, drop and vibration, Shock-mounted hard drive, Die-cast magnesium case, Resistant to water and dust,	3600mAH Lithium,	USB, Bluetooth, IEEE 802.11b, Ethernet LAN, GPS, WWAN including 1xRTT/EDGE, UMTS, and CDMA,

Table 6. 4 Tablet PC Category

6.4.2 SUB-FACTORS OF 'WIRELESS NETWORK'

There are many types of wireless networks, each of which has various features in terms of the data rate, coverage, and frequency. A review of different types of wireless networks can be found in Section 3.5. The identification of sub-factors of the wireless network focuses on the implementation of mobile computing in managing on-site construction information. Because this research concentrates on the implementation of mobile computing technologies instead of research in computing science, the detailed technical issues in the area of computing science, such as algorithm, mobile IP, topologies and other mobile protocols, are not in the scope of this research. The sub-factors of the wireless network are identified and explained as follows:

- **Technological Standard.** Wireless networks can be classified into different categories, each of which have different technological standards. For example, the Wireless Wide Area Network (WWAN) is one type of wireless network that has been developed to contain a number of technological standards such as Wireless Access Protocol (WAP), General Packet Radio Service (GPRS), and third Generation (3G). All of these technological standards have general features of WWAN, but each of them has its own specific features such as the protocol, hardware requirement, and communication standards.
- **Data Rate.** Data rate refers to the speed at which the amount of digital data can be transferred from one place to another by wireless networks and is measured in kilobits per second or megabits per second (Kbps/Mbps). In general, the greater the bandwidth of the network, the higher the data transfer rate. Normally, the data rate of wired networks is much higher than wireless networks, and the data rate of Wireless Local Area Networks are higher than Wireless Wide Area Networks.

- **Frequency.** Frequency in this framework refers to radio frequency; that portion of the electromagnetic spectrum in which electromagnetic waves can be generated by alternating current fed to an antenna. Wireless networks can only transfer digital data in a specific frequency band and different types of wireless networks have different frequency band requirements. Wireless Wide Area Networks operate in the licensed frequency band and each type of WWAN for providing wireless communication is based on obtaining services from a provider who has obtained a portion of spectrum from the FCC. Varying from WWAN, Wireless Local Area Networks operate in unlicensed bands, which means that the WLAN user does not need to obtain a license. Ensuring the compliance of the system with FCC regulation is normally the responsibility of the wireless system manufacturer.
- **Geographic Coverage.** Geographic coverage refers to the area in which mobile computers can connect to wireless networks and transfer or receive digital data. The geographic coverage of different wireless network ranges from within several metres to over thousands of kilometres. As an example, the coverage area of IrDA is within 2-5 metres; by contrast, satellite communication has earth-wide coverage.
- **Standard Feature.** Each technological standard has specific features that have an influence on the selection and implementation of the whole mobile computing system. In order to fully explore the potential and select the appropriate mobile computing technologies, the features of each technological standard should be identified.

According to their technological features and geography coverage, wireless networks can be grouped into the following four general categories:

- **Wireless Wide Area Network.** The Wireless Wide Area Network normally refers to cellular telephone systems that span over a country or even the world, but only support low bandwidths (several Kbps) for digital data communication. However, the new emerging third Generation (3G) technology can offer theoretical data speeds from 384 Kbps up to 2 Mbps. Previously, services of WWAN have focused primarily on voice communication, but there has been a recent trend to providing mobile data services. Typical WWAN technological standards consist of WAP, GPRS and 3G, see Table 6.5.
- **Wireless Local Area Network.** Compared with WWAN, the WLAN provides high data rate access but the geography coverage is limited. The most common way to access a wireless local area network is through a network interface card (NIC), which then communicates with a base station (Access Point) located in the vicinity. The most common protocols are IEEE802.11b and HomeRF (Table 6.6).
- **Wireless Personal Area Network.** The Wireless Personal Area Network typically covers a few metres surrounding a user's workspace and provides the ability to synchronise computer, transfer files and gain access to local peripherals like printers and a range of pocket hardware. Typical technological standards are Bluetooth and IrDa, see Table 6.7.
- **Satellite Communication.** Satellites can be viewed as expensive base stations providing wide-area coverage (Table 6.8). They can provide services similar to those provided by cellular phone networks. These services typically include limited quality two-way voice, circuit-switched or packet-switched data, and paging. The advantage of satellite communication is its capability to cover a widespread area, but the cost is much more expensive than other networks.

	Technological Standard		Data Rate	Frequency	Geographic Coverage	Standard Feature
Wireless Wide Area Network (WWAN)	GSM	WAP	9.6Kbps-14.4Kbps	200kHz	Nationwide coverage in UK, rural areas may have limited QOS.	2G, circuit switching, mobile Internet-like services from telecommunication operators, technologies need: QAP-gateway, WAP enabled mobile phone.
		GPRS	24Kbps-171.2Kbps	200kHz	Nationwide coverage in UK, rural areas may have limited QOS.	2.5G, uses upgraded radio base station, packet switching, Internet aware, always-on, supports GSM and TDMA, limited cell capacity for all users, speed lower in reality, transit delay
	3G		384Kbps-2Mbps	1885-2025MHz, and 2110-2200MHz	Major cities and towns, and limited rural areas.	UMTS, both circuit switched and packet switched, based on CDMA protocol, always-on, supports complex program applications.

Table 6. 5 The Category of Wireless Wide Area Network

	Technological Standard	Data Rate	Frequency	Geographic Coverage	Standard Feature
Wireless Local Area Network (WLAN)	IEEE802.11a	5Mbps	5GHz	Limited to access point location, geographic distance 25-600m[c]	Voice and data transfer, single tariff, high bandwidth data transfer, shorter coverage, large capacity of users.
	IEEE802.11b	11Mbps	2.4GHz		
	DECT	736kBPS	1.88GHz	Limited to access point location, geographic distance 300m-25km	Oldest standard, adopted as 3G standard, operates in unlicensed ISM 2.4Ghz band, focus on SOHO market.
	HomeRF	1Mbps	2.4GHz	Limited to access point location, geographic distance 40m	Based on DECT concept operates in same frequency band of IEE802.11b, large capacity of devices.

Table 6. 6 The Category of Wireless Local Area Network

	Technological Standard	Data Rate	Frequency	Geographic Coverage	Standard Feature
Wireless Personal Area Network (WPAN)	Bluetooth	723Kbps	2.4GHz	Limited to access point location, geographic distance 10-100m[c]	Shorter coverage, limited bandwidth data transfer, minimal hardware dimensions, low price, low power consumption, uses spread-spectrum and frequency-hopping technique, limited capacity of devices.
	IrDA	4Mbps for Data, 75Kbps for Control	N/A	Limited to access point location, geographic distance 2-5m	Shorter distant, easy to configure and use, high payload, point-to-point connection, line-of-sight for infrared beam.

Table 6. 7 The Category of Wireless Personal Area Network

	Technological Standard	Data Rate	Frequency	Geographic Coverage	Standard Feature
Satellite	Satellite	4.8Kbps	N/A	Earth wide coverage	Nationwide coverage, long transmission delays, broadcast transmission, large channel bandwidth, high price.

Table 6. 8 The Category of Satellite Network

6.4.3 SUB-FACTORS OF 'MOBILE APPLICATION'

In the three dependent primary factors, mobile application is the key factor that responds to specific characteristics of mobile computers and wireless networks and supports users' work processes by enhancing the efficiency and accuracy of information communication. After the extensive review of current commercially available application software for the construction industry, see Section 3.6, sub-factors of mobile application are identified as follows:

- **Software Function.** The software function is the task that the software can perform and the performance that users can use the software to achieve. This is the key reason why users select and use this application software and how it can assist users to carry out their information management activities. The functions of a mobile application allow users to retrieve, process, and transfer information on construction sites. As an example, mobile CAD software can support users to view, amend, modify and edit AutoCAD drawings while they stay on construction work sites (outside site offices).
- **System Requirements.** In order to fully perform the functions of mobile application software, a mobile computer should have the minimum system requirements asked by this software. Because mobile application software needs to run in both the mobile computer and desktop computer, system requirements of mobile applications are divided into front-end system requirements and back-end system requirements. The front-end system requirement refers to the fact that the hardware and Operating System of a mobile computer should be compatible with this mobile application and have enough capability to run it. The back-end system requirement normally focuses

on the compatibility of the mobile application software with the desktop computer system.

- **Data Transfer Method.** Mobile application software needs to retrieve construction information from or transfer it to organisational back-end systems. Typical data transfer methods between mobile computers and back-end systems include synchronisation through USB connection, Bluetooth or Infrared, and connection to Wireless Local Area Networks or Wireless Wide Area Networks.
- **Information Input.** Information input refers to the methods by which users input construction information into mobile application software when they use the input equipment of a mobile computer. For performing software functions, users are normally required to input construction information with various information formats. The design of information input methods for mobile applications focuses on the software perspective of Human Computer Interaction (HCI). Examples of software input methods include voice identification techniques, handwriting identification techniques, and touch-screen techniques.
- **Information Output.** Information output refers to how mobile application software can display construction information with different information formats to users through the output equipment of a mobile computer. The design of information output methods for mobile applications focuses on the software perspective of Human Computer Interaction (HCI). Examples of software output methods include the zoom in/out functions, scroll bar, and text-to-voice technique.

Mobile application software that is currently available in the market for the construction industry can be classified into three groups: Mobile CAD Application, Data Capture Application and Project Management Application.

- **Mobile CAD Application.** Construction personnel using a mobile computer equipped with mobile CAD applications can view, mark-up, create, edit and collaborate on 2D/3D AutoCAD compatible designs and digital blueprints when they are on construction work sites. Users using mobile CAD applications can contact the professionals who can provide support in the shape of design drawings on construction work sites. Most types of mobile CAD application are compatible with popular mobile computers running Windows CE, Windows Mobile or Palm Operating systems. In order to communicate the files of design drawings with desktop PCs, mobile CAD applications can exchange data with desktop PCs by using ActiveSync for Windows OS or HotSync for Palm OS. Examples of mobile CAD applications include PocketCAD, PowerCAD and ZipCAD, see Table 6.9.
- **Data Capture Application.** There are three types of data capture applications used in the construction industry, which include data capture software, bar code scanning software and wireless sensor networks. SHERPA (Stent Handheld ElectRonic Piling Assistant) is one of the mobile data capture systems, which enables users to utilise workforce driven mobile computers to collect real time piling work data in the field through a Wireless Local Area Network. A bar-code-enabled PDA application, named as the Mobile Construction Supply Chain Management system (M-ConSCM) has been developed to improve the effectiveness and convenience of information flow in a construction supply chain environment through integrating a PDA and a bar code scanner together. The Wireless Sensor Network that consists of various devices capable of a cooperative sensing task is a new innovative technology similar to the concept of Ubiquitous Computing or Pervasive Computing. A mass concrete curing management system (CMS) has been developed to investigate the possibility of applying the Wireless Sensor Network to on-site data collection processes. This

system can allow the collection, transfer, and delivery of the recorded curing temperature data automatically in real time in a Wireless Sensor Network environment. Table 6.10 shows the features of these three data capture applications.

- **Project Management Application.** Applications for construction project administration provide users with the capabilities of performing project and programme management tasks through their on-hand mobile computers. These tasks include construction activity review, activity monitoring and updating, progress management, risk management, Microsoft Project file view and update, and material and equipment management. Commercially available applications include Primavera Mobile Management, CYtools, and OnSite FDM, see Table 6.11.

CAD Application		Software Function	System Requirement: Front-end	System Requirement: Back-end	Data Transfer Method	Input Information	Output Information
CAD Application	PocketCAD	**Compatibility** (Reads and Writes DWG,DXF,DGN files, Compatible with desktop CAD software, Runs on most Pocket PCs), **Viewing** (View AutoCAD drawings, Zoom, Measure distance and angle) **Amending** (Make changes, Create units, Sketch, Create layers, Set colour, Set points, Annotate and Label) **Edit** (Edit drawings, Copy, Offset, Rotate, Move, Delete, Undo and Redo) **Measure** (Select Points on screen and get distance, angle and offset, Dimension horizontal, vertical and align) **Programmable** (Build or use custom add-ins, PunchList AddIn, Site Measurement AddIns, Printer AddIn)	Windows CE powered Pocket PC or Handheld PC minimum 16MB storage, PocketCAD software.	Pentium-based PC, Microsoft Windows Systems, Microsoft ActiveSync 3.0 or newer, Most desktop CAD software	CAD Exchanges works in conjunction with Microsoft ActiveSync. Data can be transferred by Ethernet, WLAN, USB, and Infrared.	Drawings (Graphic, text, form).	Drawings (Graphic, text, form).
	PowerCAD CE	**Compatibility** (Reads and writes FLX, DWG and DXF files, Compatible with desktop CAD software, Runs on most Pocket PCs) **Viewing** (View 2D or 3D CAD drawings, zooming and panning,) **Amending** (Mark up, create drawings, create layers, create dimensioning and hatching) **Edit** (Edit drawings using over 200 standard advanced 2D drawing tools) **Programmable** (Run Lisp and C/C++ program extensions)	Windows CE 3.0 or higher portable / wireless computing devices with 5-7MB of free space, PowerCAD CE software.	Pentium-based PC, Microsoft Windows Systems, Microsoft ActiveSync 3.0 or newer, PowerCAD pro, FelixCAD, Auto CAD	CAD Exchanges works in conjunction with Microsoft ActiveSync. Data can be transferred by Ethernet, WLAN, USB, and Infrared.	Drawings (Graphic, text, form),	Drawings (Graphic, text, form).

Table 6.9: The Category of CAD Application (1)

	PowerCAD SiteMaster	**Compatibility** (Import and export FLX, DWG, DXF, DWF, BMP and JPG files, Compatible with desktop CAD software, Runs on Pocket PC, Notebook or Tablet PC, support Bluetooth laser device) **Surveying** (Building measurement, single line walls, double line walls, floor management, laser measurements recording, check distance, camera, image functions) **CAD** (Over 200 AutoCAD 2D drawing functions, AutoCAD compatible units and layers) **Viewing** (View 2D or 3D CAD drawings, zooming and panning,) **Amending** (Mark up, create drawings, create layers, create dimensioning and hatching) **Edit** (full set of editing commands) **Programmable** (Run Lisp and C/C++ program extensions)	Windows CE based Pocket PCs, Windows CE.Net or Windows XP based Tablet PC and Notebooks, Laser measurement devices, PowerCAD, SiteMaster software.	Pentium-based PC, Microsoft Windows Systems, Microsoft ActiveSync 3.0 or newer, Most desktop CAD software.	The laser measurement device and the Pocket PC are connected by Bluetooth or a serial cable, CAD Exchanges works in conjunction with Microsoft ActiveSync. Data can be transferred by Ethernet, WLAN, USB, and Infrared.	Drawings (Graphic, text, form), Site pic (Image), Voice notes (Verbal)	Drawings (Graphic, text, form),
	ZIPCAD	**Compatibility** (Imports and exports DXF files, runs on Palm OS handhelds) **Amending** (Line, Arc, Box, Circle, Text, line offset, corner trim, measure, etc.) **Viewing** (Zoom, pan, view all, refresh, etc.) **Edit** (Select, Undo/Redo, snap preferences, layers, etc.) **Measure** (distance measurement using Bluetooth compatible Leica Disto Plus laser distance meter)	Palm Os 3.1 or later handhelds, Palm RAM required 639K, SD Card Support, ZipCAD software	Pentium-based PC, Microsoft Windows Systems, HotSync system, Most desktop CAD software	CAD Exchanges works in conjunction with HotSync. Data can be transferred by Infrared, LAN, Wi-Fi, Bluetooth.	Drawings (Graphic, text, form), Punch list information (Text, Form).	Drawings (Graphic, text, form).

Table 6. 9 The Category of CAD Application (2)

		Software Function	System Requirement		Data Transfer Method	Input Information	Output Information
			Front-end	Back-end			
Data Capture Application	SHERPA	Provides real-time data capture to the site workforce for the recording of pile construction information.	A touch-screen Windows CE tablet computer with IEEE 802.11b wireless card, Microsoft Access front-end database.	Pentium-based PC, Microsoft Windows Systems, Microsoft Access database.,	IEEE 802.11b WLAN.	Pile construction information (Form).	Pile construction information (Form, Text, Graphic).
	CMS	Measures the concrete curing temperature and estimate in-place concrete strength.	Thermal sensors, data-logger, RF(radio frequency) modem.	Pentium-based PC, Strength estimation software.Microsoft Windows Systems,	Radio frequency.	Temperature of concrete (Digital signal).	Temperature, maturity, and strength, (Graphic, text, form).
	M-ConSCM	Improves construction supply chain information acquisition on site and provides an information-sharing platform among all participants of the construction chain utilizing web technology and bar-code-enabled PDA.	PDA with plugged bar code scanner, M-ConSCM client side, Palm OS or Windows CE, Palm Scanner or iPAQ Scanner, PDA database.	Pentium-based PC, Microsoft Windows Systems, Portal, M-ConSCM server side, Web browser, Server database.	WLAN, Internet.	Material information, Equipment information, Progress information.	Material information, Equipment information, Progress information, Sub-contractor information.

Table 6. 10 The Category of Data Capture Application

		Software Function	System Requirement		Data Transfer Method	Input Information	Output Information
			Front-end	Back-end			
Project Management Application	Primavera Mobile Management	Reviews and status construction activities. Monitors and updates construction activity progress.	Most recent devices with Palm OS 4.0 or earlier or Microsoft Pocket PC 2002 or earlier.	Windows 2000 Professional SP4, XP Professional SP2. Primavera SDK must be installed. 15MB disk drive space and 128MB of RAM minimum. Primavera 3.5.1	Microsoft ActiveSync.Data can be transferred by Ethernet, WLAN, USB, and Infrared, HotSync.	Progress information, Schedule information, (Form, Text)	Progress information, Schedule information, (Form, Text)
	CYtools: Project Management Tools	Creates, updates and manages construction action items, Views and updates Microsoft Project files on Pocket PC, Integrates a risk management process with Microsoft Project data files, Reports project status.	Most Pocket PCs with Windows Mobile 2002 or 2003.	Windows 98, ME, 2000 or XP, Minimum hard disk space 10MB and 1MB for files, Project 2000, 2002 or 2003, ActiveSync, Outlook.	Microsoft ActiveSync, Data can be transferred by Ethernet, WLAN, USB, and Infrared.	Progress information, Schedule information, Risk management information, (Text, Form, Graphic, Verbal,)	Progress information, Schedule information, Risk management information, (Text, Form, Graphic, Verbal,)
	OnSite: Field Data Management	Creates, sort, manage, distribute and upload punchlists, Complete, manage, and distribute daily reports, field conditions, events, crew info, manpower data, equipment info and safety notices.	Most handheld device with Palm OS 3.0, Minimum 2MB of memory.	Windows 98, ME, 2000 or XP.	HotSync, Data can be transferred by Infrared, LAN, Wi-Fi, Bluetooth.	Punchilists, daily reports, field conditions, events, crew info, manpower data, equipment info and safety notices, (Text, Form, Graphic, Verbal,)	Punchilists, daily reports, field conditions, events, crew info, manpower data, equipment info and safety notices, (Text, Form, Graphic, Verbal,)

Table 6. 11 The Category of Project Management Application

6.4.4 SUB-FACTORS OF 'USER'

The independent factor 'user' refers to construction personnel who manage on-site information supported by mobile computing systems on construction site. The user is a key primary factor in this framework because all components of a mobile computing system should have sufficient capability to meet user's needs in managing required information. Therefore, it is essential to identify the characteristics of mobile users who determine the selection of mobile computing technologies and are a key consideration in the design of mobile computing systems. The identification of sub-factors for the primary factor 'user' is based on the second research step of using case study analysis (Section 5.3) and respondent profiles provided by the third step, the survey (Section 5.42). These sub-factors are listed and explained as follows:

- **Role.** According to the case studies and the survey research, roles of construction personnel include the project manager, quantity surveyor, general foreman, civil engineer, site engineer, quality administrator, officer manager, and others. The variety of roles on construction sites are normally affected by project stages, types and size of project.
- **Responsibility.** In the construction of a project, each construction role has various responsibilities. For example, the responsibilities of a foreman consist of reading and interpreting drawings, assigning and inspecting works, organising employees, and coordinating with other construction personnel. The responsibilities of construction roles determine their information needs and information management activities.
- **On-site Time.** During project construction, project team members need to visit construction work sites, but the length of time personnel spend outdoors differs.

Some construction personnel including the foreman, site supervisor and site engineer spend more than 50% of their work time on construction work sites, but some office-based managers only need occasional visits to work sites.

- **Mobility.** User's mobility refers to the covered areas on construction work sites where users carry out their daily construction activities. Some types of mobile users, such as a foreman, need to visit most areas on work sites, but other users like a project manager only need to inspect specific site points.
- **Computer Skills.** Because this framework aims to explore how mobile computing can assist construction personnel to manage on-site information, it requires construction users to have basic computer related knowledge and the ability to use relevant mobile IT tools. If users lack related mobile computing knowledge, appropriate training and education are required.
- **Retrieved Information.** Users on construction work sites need to retrieve various types of information to support their construction activities. One of the most important types of information needed by users on construction work sites is drawings that are required by most construction personnel to assist their work.
- **Transferred Information.** Transferred information refers to the information that construction personnel collect and transfer from construction work sites to organisational information systems in order to facilitate managers to monitor and control the progress of a project.
- **Information Processing.** Construction personnel on construction work sites need to manage and process information. As an example, site supervisors may need to view drawings, mark up differences on design drawings, measure the real distance, check and clarify design data, and collect progress data.

According to the definition of construction workers, see Section 1.7.2, the factor 'user' is considered to include three types of construction workers: fixed worker, semi-fixed worker, and mobile worker, see Table 6.12.

- **Fixed Worker.** A fixed worker normally works at site offices, and uses the desktops or laptops with a connection to a fixed Local Area Network (LAN) or a Wireless LAN (WLAN) where cabling is not appropriate, which is called "fixed wireless". Fixed workers hardly visit construction work sites and normally remain at site offices to conduct their work. Some examples of fixed workers include the client representative, finance officer, and business development manager.
- **Semi-fixed Worker.** Semi-fixed workers normally use desktops or laptops at site offices, but they have to move from place to place at construction work sites in between working periods. Their communication infrastructure can be either a fixed LAN at site offices or a wireless network providing coverage in the area of construction work sites. Typical examples consist of the project manager, construction director, quality manager, and safety manager.
- **Mobile Worker.** Mobile workers normally use mobile computers when moving around construction work sites or remaining at site offices for a short period of time. Their communication infrastructure can be either a WLAN or a mobile network (radio or telephone) providing coverage in their work areas. The site engineer, general foreman and site supervisor are typical mobile workers.

User Type / User Profile	Mobile Worker	Semi-Fixed Worker	Fixed Worker
Role	General Foreman, Site Engineer, Site Supervisor, Site Agent.	Project Manager, Managing Director, Principal Clerk, Construction Director.	Client Representative, Finance Officer, Proposal Manager, Contract Manager, Building Estimator.
Responsibility	Inspects and instructs construction process. Organizes and coordinates employee in function on a projects. Reads and interprets drawings. Administers union agreements and safety enforcement.	Organizes and supervises onsite foremen and managers, Organizes and supervises equipment, materials, and construction processes, Directs all construction activities, Coordinates with all construction participants, Directs and assumes responsibility for project's field work, Reviews, inspects, evaluates and reports quality and progress of the project.	Supervises and administers finance issues, Maintain relationships and communicate with clients, Administers contract and negotiates with other project participants, Develops business.
Onsite Time	They normally move around at work sites or remain at site office for short periods time.	They normally remain at site offices, but have to move around at work sites in between working periods.	They hardly visit construction work sites and normally remain at site offices.
Mobility	Mobility covers most area of work sites, Travel between multi sites.	Visit specific area of work sites, Travel between multi sites.	Few areas of work sites.
Computer Skill	Appropriate knowledge on mobile computers and mobile application software.	Appropriate knowledge on mobile computers and mobile application software.	Poor skills with mobile devices and mobile applications.
Retrieved Information	Drawings, Material Information, Equipment Information, Progress, Sub-contractor, Labour, Safety Information, Quality Information.	Drawings, Progress, Contract, Design Clarifications, Safety Information, Quality Information.	Drawings, Progress.
Transferred Information	RFI, Material Update, Equipment Update, Site Visit Record, Schedule Update, Progress Update, Sub-contractor Performance Report, Quality Report, Labour Record, Safety Record.	RFI, Schedule Update, Progress Update, Site Visit Record, Quality Report, Safety Record.	RFI, Schedule Update, Progress Update.
Information Processing	View, Edit, Draw, Mark up, Measure, Write, Update, Check, Clarify, Collect.	View, Mark up, Write, Update, Check, Clarify.	View, Clarify.

Table 6. 12 The Sub-factor of 'User' and Types of Mobile Workers

6.4.5 SUB-FACTORS OF 'CONSTRUCTION INFORMATION'

In this framework, the factor 'construction information' particularly refers to on-site information that is retrieved to and transferred from construction sites to support construction mobile users in conducting their construction activities. The exploration of construction information includes the literature review (Section 2.4), on-site investigation through case study analysis (Section 5.3), and a survey of the mechanisms of on-site information communication (Sections 5.4.3 and 5.4.4). Features of construction information consist of the information format, file size, on-site information flow, on-site information processing, source, and transfer destination. The sub-factors of 'construction information' are listed as follows. The types of construction information are shown in Table 6.13.

- **Information Type.** Construction sites are information intensive environments in which construction personnel need to receive or transfer many types of construction information. On-site information identified in the survey includes requests for information, materials management, equipment management, cost management, schedule and means and methods, site records, submittals, and safety information.
- **Information Format.** In this framework, the nature of construction information is considered to be the formats of text, graphic, form, image and verbal communication. Each type of construction information has one or more information formats. As an example, the major format of construction drawings is graphic, but drawings are also represented by the formats of image and text.
- **File Size.** Construction information that users retrieve on work sites are normally stored on documents that are either paper-based files or digital mediums. Paper-based files are measured by the size and quantity of paper. Digital files are normally measured by Kilo Byte or Mega Byte. For example, construction drawings are

stored on large size papers such as A0 and A1 size, but some kinds of information such as progress or schedule can be presented on A4 papers. The digital files of construction drawings normally occupy more computer storage space than the digital files of progress information.

- **Information Flow.** Information flow refers to whether construction information is retrieved from information sources to construction work sites or information is collected and transferred from the construction work site to information destinations including project information systems or other professionals.
- **Information Processing.** Information processing refers to the information management activities of construction mobile users. For example, activities of processing drawings include the view, edition, amendment, mark up and measurement.
- **Information Source.** Information sources are the places or people from which mobile users retrieve information on construction work sites. Information sources can be people, computer systems, or document storages.
- **Information Destination.** Information destinations are the places or people to which mobile users transfer construction information on work sites. Information destinations can be people, computer systems, or document storages.

Information Type	Information Format	File Size	Information flow	Information Processing	Information Source	Information Destination
Drawing	Text, Graphic	Large	Retrieve Transfer	Viewing, Editing, Drawing, Marking up, Measuring	People, Computer System, Document Storage	Computer System, Document Storage
Material Management Information	Text, Form, Verbal	Medium	Retrieve Transfer	Viewing, Writing, Checking, Updating	People, Computer System	People, Computer System
Equipment Management Information	Text, Form, Verbal	Medium	Retrieve, Transfer	Viewing, Writing, Checking, Updating	People, Computer System	People, Computer System
Contract Information	Text, Graphic	Large	Retrieve	Viewing, Checking	Computer System, Document Storage	Computer System, Document Storage
Schedule and Progress Information	Text, Graphic, Verbal	Medium	Retrieve Transfer	Viewing, Writing, Checking, Updating,	People, Computer System	People, Computer System
Design Clarification	Text, Graphic, Verbal	Medium	Retrieve	Viewing, Checking, Updating, Clarifying	People, Computer System, Document Storage	Computer System, Document Storage
Construction and Engineering Methods	Text, Graphic, Image, Verbal	Large	Retrieve	Viewing, Checking	People, Computer System, Document Storage	People, Computer System, Document Storage
Sub-contractor Information	Text, Graphic, Form, Verbal	Medium	Retrieve Transfer	Viewing, Writing, Checking, Updating,	People, Computer System, Document Storage	People, Computer System, Document Storage
Labour Information	Text, Form	Medium	Retrieve Transfer	Viewing, Checking, Collecting, Updating,	People, Computer System, Document Storage	People, Computer System, Document Storage
Quality Control Information	Text, Form, Verbal	Medium	Retrieve Transfer	Viewing, Checking, Collecting, Updating	People, Computer System, Document Storage	People, Computer System, Document Storage
Safety Information	Text, Form, Verbal	Medium	Retrieve Transfer	Viewing, Checking, Collecting, Updating	People, Computer System, Document Storage	People, Computer System, Document Storage
Site Visit Record	Text, Form	Medium	Transfer	Writing, Updating	Computer System, Document Storage	Computer System, Document Storage

Table 6. 13 The Sub-factors and Types of Construction Information

6.4.6 SUB-FACTORS OF 'CONSTRUCTION SITE'

In this framework, the factor 'construction site' is considered as having two main components: construction work site and site office. The construction work site refers to the areas of material storage spaces, actual operation places, equipment locations and other fields outside site offices. The construction site office is the headquarters for managerial personnel, such as the project manager, foreman, and engineer. The environment and situations of construction sites are described from the findings of the case studies (Section 5.3). With regard to how construction sites can have an effect on the use of mobile computing, the sub-factors of the primary factor 'construction site' in this framework include site size, physical environment and on-site construction process, see Table 6.14.

- **Site Size.** The size of a construction site is considered to be the types of multi-sites, small-size, medium-size, and large-size site.
- **Site Environment.** Because construction projects are normally conducted outdoors, the physical environment of a site is one major factor that has an influence on the use of mobile computing on construction work sites. The physical environment includes the general weather conditions during project construction, and the working conditions such as dust, moist, or high building.
- **On-site Construction Process.** During the project construction period, there are lots of construction processes carried out on work sites. In order to implement mobile computing technologies, it is essential to identify the construction processes that are suitable for mobile computing before selecting appropriate technologies.

Site Size	Site Environment	On-site Construction Process
Multi-sites, Small-size (50 – 100m^c), Medium-size(100m^c - 500m^c) Large-size(Over 500m^c)	Weather condition, Temperature, Dust, Moist	Pilling works, Progress records, Site diaries, Resource management, Quality inspections, Maintenance, Health and safety, Site design problem resolution

Table 6. 14 Sub-factors of Construction Site

6.5 INTERRELATIONSHIPS BETWEEN PRIMARY FACTORS

There are three major connections in the developed framework, which include the relationships between the three dependent factors, relationships between the three independent factors, and relationships between the independent factors and the dependent factors. After identifying sub-factors for each primary factor, the three major connections can be further explored in detail.

6.5.1 INTERRELATIONSHIPS BETWEEN DEPENDENT FACTORS

As discussed in Section 6.2, the three dependent factors including 'mobile computer', 'wireless network' and 'mobile application', are the key components of the concept of mobile computing. Before discussing their applications in construction site information management, it is necessary to explore the interrelationships between these three factors. Figure 6.2 shows links between their sub-factors in order to provide an insight into the interrelationships between two primary factors. These relationships are listed as follows:

- **Mobile Computer and Mobile Application.** The mobile application is the software that runs on mobile computers to support user's work processes by responding to specific features of mobile computers and wireless networks. In order to fully perform its functions, a mobile application requires that the operating system of a mobile computer should be compatible with this application software, its processor should have the adequate speed and capability to run this software, and the mobile computer should have sufficient storage capacity to store all the data required by this software. On the other hand, the mobile computer's system performance including operating system, processor speed and storage capacity determines what kinds of mobile application can run on this mobile computer. A mobile computer with low system performance can only run limited software with simple functions. Mobile applications can retrieve, transfer or synchronise data with organisational information systems or personal desktop computers through different data transfer methods. This requires mobile computers to be equipped with corresponding connection methods such as USB, Bluetooth, IrDA, LAN, WLAN, WWAN, or the GPS receiver. Another link between mobile computers and mobile application software is the consideration of Human Computer Interaction (HCI) from both the software perspective and hardware perspective. Most current commercially available mobile computers and application software have multi data input/output approaches for communication between users and mobile computers. Construction information inputted into application software requires that mobile computers are equipped with corresponding data input hardware such as the mini-keyboard, touch-sensitive soft keyboards, pen-stylus and touch-screen. The output of construction information provided and presented by mobile applications contains different types of information formats and requires relevant information output hardware for mobile computers. For example, if the provided information is construction drawings, the bigger the screen size and the higher the screen resolution, the clearer and more accurate will be the display. If the application software can transfer voice, a mobile computer should have relevant hardware devices such as a speaker, microphone or headset.

- **Mobile Computer and Wireless Network.** Because of the need for information communication between mobile computers and organisational information systems, mobile computers have two major connection methods: synchronisation with desktop computers and connection to wireless networks. Typically, a smart phone and a pocket PC phone can connect to cellular phone networks (Wireless Wide Area Network) with the technological standards of GSM and 3G. A pocket PC or a pocket PC phone can access Wireless Local Area Networks with the technological standards of IEEE802.11a and HomeRF. Additionally, a Tablet PC normally has more choices for the connection to wireless networks such as WWAN, WLAN or both of them. If different wireless networks are available, the choice of a specific wireless network for a mobile computer should consider the convenience, technique standards, the features of each type of wireless network, and the compatibility between the mobile computer and the wireless network.
- **Mobile Application and Wireless Network.** The interrelationships between mobile applications and wireless networks focus on the selection of wireless networks for specific application software according to the technical features of the network. In order to increase the efficiency of data communication and reduce running costs, the mobile application that can connect to different wireless networks may select a suitable network by considering the data transfer rate, geographic coverage and network standard features including the cost of services, always-on ability, Internet

aware, voice or data transfer ability, capacity of users and power consumption. For example, the mobile application aiming to retrieve large construction files such as drawings or video clips requires that the selected wireless network should have a high speed of data transfer rate and enough bandwidth to transfer files within the required time period.

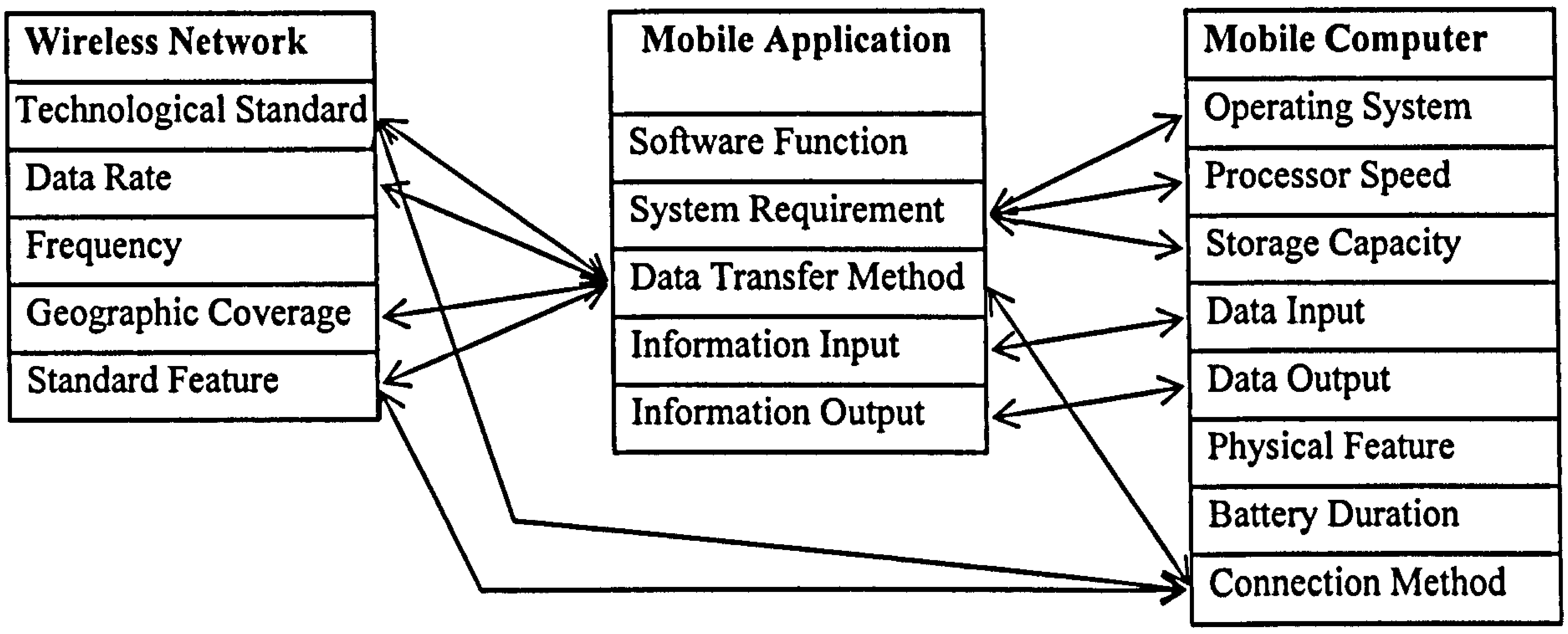


Figure 6. 2 Interrelationships between Dependent Factors

6.5.2 INTERRELATIONSHIPS BETWEEN INDEPENDENT FACTORS

In this framework, the three independent factors: 'user', 'construction information' and 'construction site', determine the use of mobile computing in a particular construction circumstance. In order to fully understand the construction circumstance in which mobile computing is applied, interrelationships between the three independent factors should be identified and explained in great detail. Figure 6.3 shows the links between sub-factors for each pair of independent factors and the detailed relationships are listed as follows:

- **User and Construction Information.** According to previous research and the findings from the survey research, the information needs of mobile users on construction sites are inextricably linked to their management responsibilities. In this framework, the sub-factor 'responsibility' is linked to the sub-factors of 'information type' and 'information flow', which indicates that mobile users with different construction responsibilities need to retrieve or transfer the relevant types of information on construction sites. On construction work sites, mobile users need to retrieve different types of information to support their work from various information sources including other construction professionals, computer systems and document storages. In contrast, construction information collected on work sites should be transferred to different information destinations including managerial people, computer systems or document storages. The link between the two sub-factors of information processing refers to the information management activities that users use to manage and process construction information on work sites. These information management activities include viewing drawings, marking up differences, measuring real distance, checking and clarifying figures, collecting data, and updating records.
- **Construction Information and Construction Site.** During the period of project construction, there is a large number of construction processes carried out on construction work sites. Each construction process contains lots of information management activities, such as information communication, information transfers, information retrievals and information processing. In this framework, the on-site construction process as one of the sub-factors of 'construction site' is linked to other sub-factors including the information type, information flow and information process. The interrelations between these sub-factors refer to the consideration that

construction information involved in a construction process, the directions of information flows and information activities carried out during the process should be clearly identified and mapped out in order to evaluate whether this construction process is suitable for applying mobile computing technologies.

- **User and Construction Site.** Construction activities are actually carried out by construction personnel on construction sites. People undertaking these roles in the construction project are normally involved in different on-site construction processes. For example, managerial people such as project managers may monitor, supervise and inspect most on-site construction processes; in contrast, sub-contractors may only conduct single or a few construction processes based on their responsibilities.

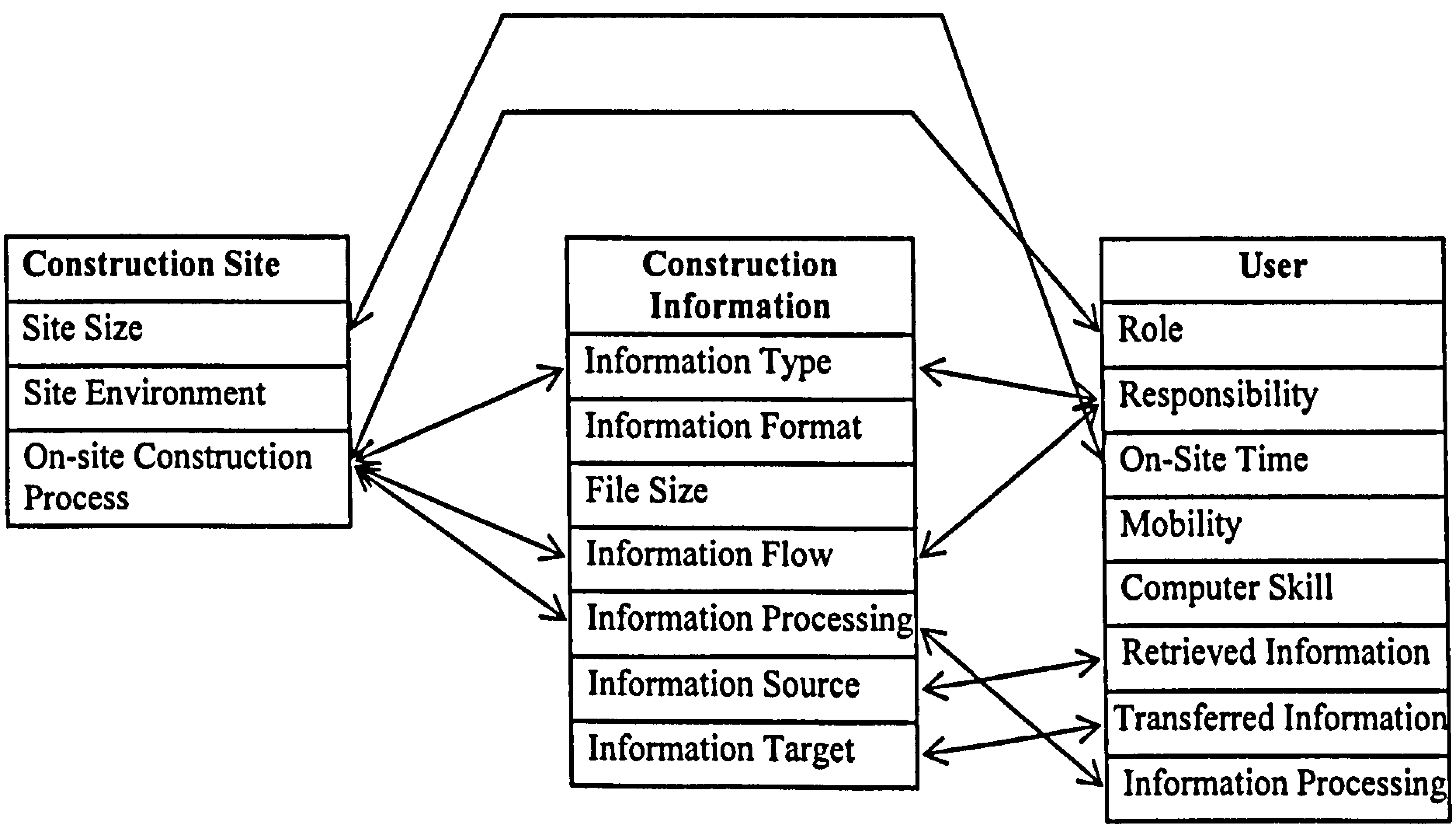


Figure 6. 3 Interrelationships between Independent Factors

6.5.3 INTERRELATIONSHIPS BETWEEN 'USER' AND 'MOBILE COMPUTING'

The 'user' in this framework is the construction personnel who use mobile computing technologies to assist their information management tasks on construction sites. The interrelationship between the 'user' and 'mobile computing' refers to the implementation of mobile computing from user's perspective with the consideration of how the user interacts with mobile computing systems to meet its specific information needs. Figure 6.4 shows links between identified sub-factors of 'user' and 'mobile computing', which are explained as follows:

- **User and Mobile Computer.** One of the key issues of using mobile computing in construction is the fact that most users need to interact with mobile computers to perform their information management tasks. Therefore, the interrelationship between the 'user' and 'mobile computer' focuses on Human Computer Interaction (HCI) for the hardware perspective. HCI designs from the hardware perspective require that data input and output equipment of a mobile computer should ensure that users can process information on construction work sites efficiently, effectively and satisfactorily. General data input equipment for mobile computers include the phone keypad, navigation button, QWERTY keyboard, pen-stylus and touch-screen, handwriting recognition, touch-sensitive soft keyboards, portable keyboards, voice recognition, voice transfer, and camera for picture capture and video recorder. Because current commercially available mobile computers are normally equipped with more than one data input method, the selection of data input methods should aim to increase convenience, efficiency and accuracy with the consideration of information management tasks, the supported construction processes and the environment of construction sites. The 'data output' sub-factor represents the way that mobile computers present, display and provide construction information to mobile users. There are two major pieces of information output equipment: the screen for the information formats of graphic, text, form and image, and the speaker for verbal communication. The selection of mobile computers should pertain to its screen size, colour quality and resolution in order to ensure that the selected screen can precisely display required construction information for users. Because mobile computers are normally used outside site offices, away from a power outlet, another link between the user and mobile computer is the necessity that the battery time of a mobile computer should persist for a long enough period of time when the user is outdoors on construction work sites.

- **User and Mobile Application.** Construction personnel can perform the functions of mobile application software to enhance the efficiency of information communication on construction sites. Based on their roles in construction projects, different mobile users have different requirements for software functions. For example, a project manager needs software functions including reviewing drawings, monitoring progress, updating schedules and distributing records, and a site engineer may need different software functions such as the engineering calculations and review drawings. Therefore, the role of a user decides the selection and implementation of mobile application software for the specific information requirements. Mobile users should have essential computer skills to operate mobile computers and use mobile application software. If users lack required computer skills and knowledge, training and education are necessary for them before the use of relevant mobile computing technologies. The links between user's 'information processing' and 'input'/'output' of mobile application concentrate on Human Computer Interaction (HCI) from the software perspective. The design of human computer interface for mobile application that aims to increase the efficiency and convenience of data input/output from the software perspective should take account of the issues including the environment of construction sites, the mobility of users, the various hardware input/output equipment, and the tasks that the mobile application will perform. In order to retrieve and transfer information on work sites, users need to select appropriate data transfer methods provided by mobile application. Mobile applications normally have two major data transfer methods including the synchronisation through USB connection, Bluetooth or Infrared, and the connection to Wireless Local Area Network or Wireless Wide Area Networks.

- **User and Wireless Network.** Interrelationships between the factors 'user' and 'wireless network' concern the geographic coverage of a wireless network that should cover all the areas where a user moves around on the construction work sites. The selection of technological standards should take account of user's mobility. For example, a Wireless Local Area Network is suitable for users who need to visit only one construction work site with limited areas, but is not appropriate for users who visit more than one construction work site with large geographic areas. Wireless Wide Area Networks such as WAP, GPRS and 3G can be the selection for users who use Pocket PC Phones connected to cellular phone networks that provide the coverage of large geographic areas including one or more construction sites.

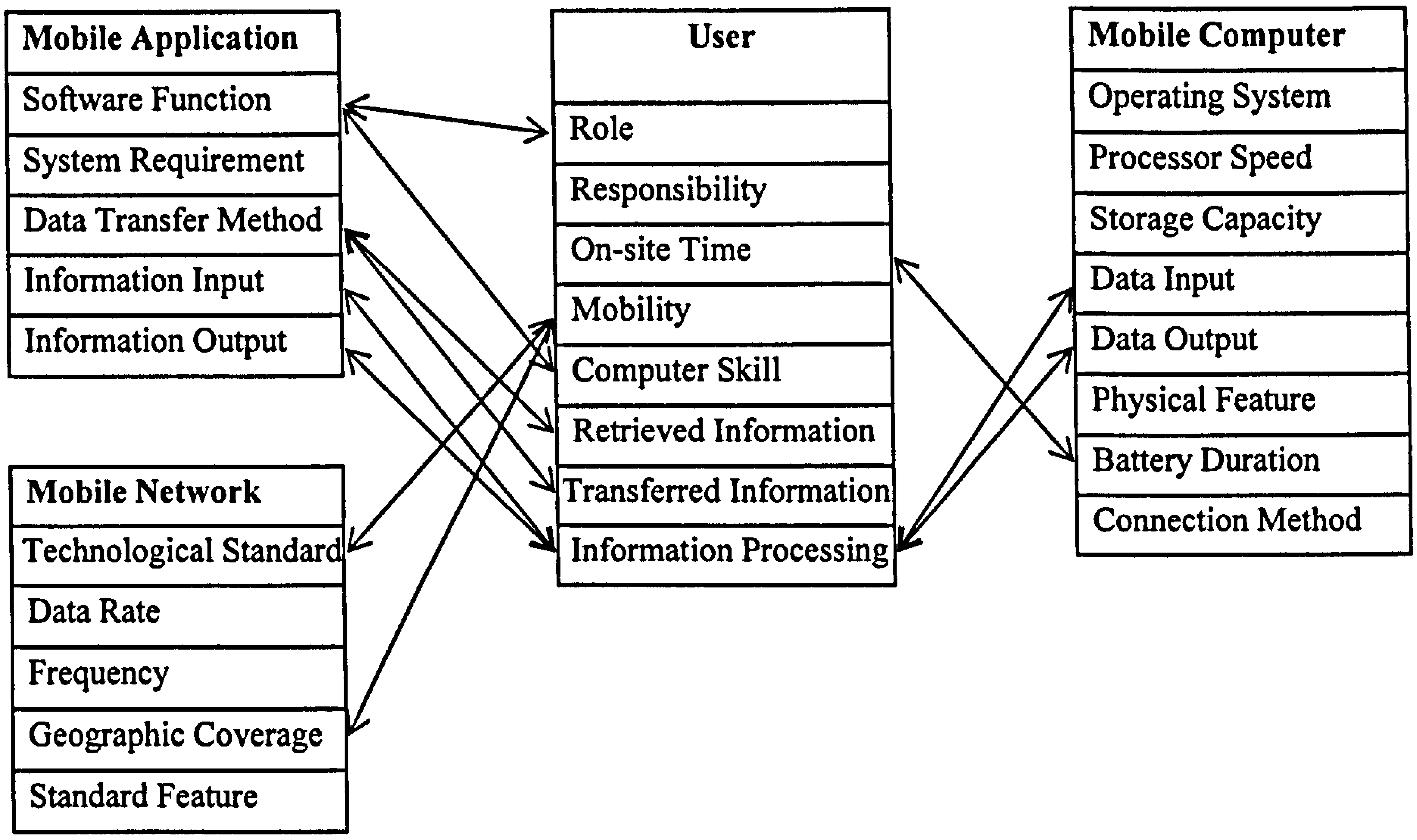


Figure 6. 4 Interrelationships between 'User' and 'Mobile Computing'

6.5.4 INTERRELATIONSHIPS BETWEEN 'CONSTRUCTION INFORMATION' AND 'MOBILE COMPUTING'

Construction information referring to the on-site information that users retrieve to or transfer from construction sites have its own characteristics compared with other information types. The use of mobile computing systems in managing construction information should address these specific features. The sub-framework in Figure 6.5 also shows the interrelationships between construction information and mobile computing and is discussed as follows:

- **Construction Information and Mobile Computer.** The link between construction information and mobile computer concentrates on how mobile computer presents and provides specific construction information to users. One of the features of construction information is that it is represented in various formats including graphic, imagine, text, form and verbal communication. The format of construction information has a major impact on the output method of the mobile computer; similarly the output mechanism of the mobile computer can restrict the output format of construction information. For example, when a user needs the mobile computer to display construction drawings, the screen size of mobile computer limits the expressional scope of drawings. The requirement of displaying large size drawings can be fulfilled from the hardware aspect by choosing a mobile computer with larger size screen. In addition, the input methods of mobile computer including keyboard, touch-screen input and voice recognition input, determine what types of information format can be inputted and how efficiently this can be done. The storage capability of the mobile device should be able to store the necessary information files; on the other hand, the file size for mobile application software should be smaller and only keep necessary software functions in order to fit in the limited storage capability.

- **Construction Information and Mobile application.** Information format also has an influence on the software perspective of data input or output. For example, the requirement of displaying large size drawings can be fulfilled from the software aspect through the design of drawing viewer software with the functions of zoom out, zoom in, scrolling, mobbing and layout. Functions of mobile application should fulfil the requirements of information processing performed by users on construction work sites. Users' information processing activities include viewing drawings, editing files, making notes, and taking pictures or videos, which should be carefully considered when selecting appropriate mobile application software. The information flow of construction information refers to whether information is retrieved from other construction employees to construction work sites or is transferred from construction work site to other project information systems or employees. Data transfer methods of mobile application should meet the requirements of information flow with efficiency, effectiveness and convenience.

- **Construction Information and Wireless Network.** The selection of wireless networks for construction information transfer should consider the file size of information that need to transfer and whether the network's data rate or bandwidth have the ability to transfer information reliably and without delay. Other factors that affect the selection of technological standard for wireless network are the information retrieval source and the information transfer destination. If the information source is the computer system in a site office, Wireless Local Area Network that covers the whole construction site is enough for a user to retrieve information by using mobile computer. If the information source is construction personnel, a user can simply use a Smart Phone or Pocket PC Phone to make a phone call via the cell phone network or IP phone network.

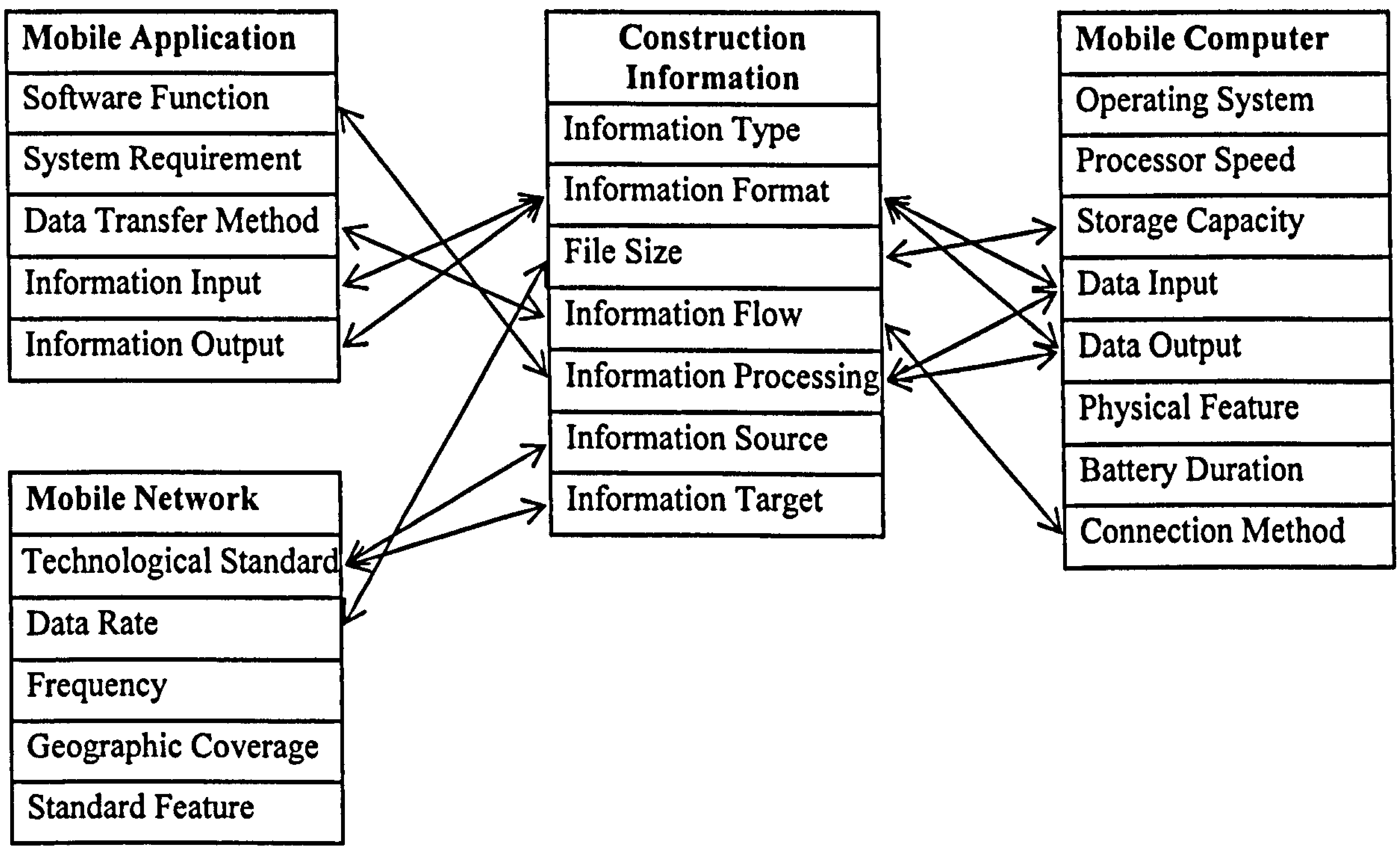


Figure 6. 5 Interrelationships between 'Construction Information' and 'Mobile Computing'

6.5.5 INTERRELATIONSHIPS BETWEEN 'CONSTRUCTION SITE' AND 'MOBILE COMPUTING'

In this framework, the factor 'construction site' is considered to be two main components: the work site and site office. The work site is the area outside site offices, and the site office is the headquarters for managerial personnel and the storage place for construction documents. The factors of a construction site that have an influence on the use of mobile computing include the site size, physical environment and on-site construction process. Figure 6.6 shows the links between the construction site and mobile computing, which are explained as follows:

- **Construction Site and Mobile Computer.** Because construction projects are normally conducted outdoors, a site environment is a major factor that has an influence on the use of mobile computing on construction sites. The site environment includes the general weather conditions in the duration of project construction, temperature, and the working conditions such as the dust, moist, or high building. The links between construction sites and mobile computers indicate that users should consider the site environment before selecting the relevant physical features of a mobile computer. For example, mobile computers can be equipped with the rugged screen, water and dust protection, and crush resistant to confront difficult site environments. The HCI design of a mobile computer should take account of the difficult situation on sites. For example, for safety reasons, the data input equipment of a mobile computer and the Human Computer Interaction for mobile software should be designed as easy and simple as possible for users who operate them on construction work sites.
- **Construction Site and Mobile Application.** Because there a large number of construction processes conducted on construction sites, it is essential to identify the

construction processes that are suitable for the implementation of mobile computing and therefore to select or design related mobile application software for those processes. For a specific construction process, the functions of mobile application software should be able to assist users to carry out their information management activities. As an example, mobile CAD software can support users with the view, amendment, modification and edit of AutoCAD drawings while they are on work sites.

- **Construction Site and Wireless Network.** The interrelationships between construction sites and wireless networks mean that the selection of wireless networks is mainly dependent on the features of a construction site. According to the size of a construction site, the selected wireless network should have enough geographic coverage to cover all areas of the site with essential signal strength. The geographical features of a construction site include the site shape, on-site superstructure, variation at working levels, and large spoil heaps. All these geographical features have a major influence on the signal strength of a wireless network. For example, the on-site superstructure construction and spoil heaps may obstruct the signal propagation of a wireless networks. Geographical features also require some specific network configuration, such as the number and position of antenna and amplifier, and the use of wireless network cell. According to the number of construction sites, information system designers should consider how these sites can be integrated together through appropriate networks. The location of site offices is important for the topology of wireless networks and determines how a wireless network can be configured.

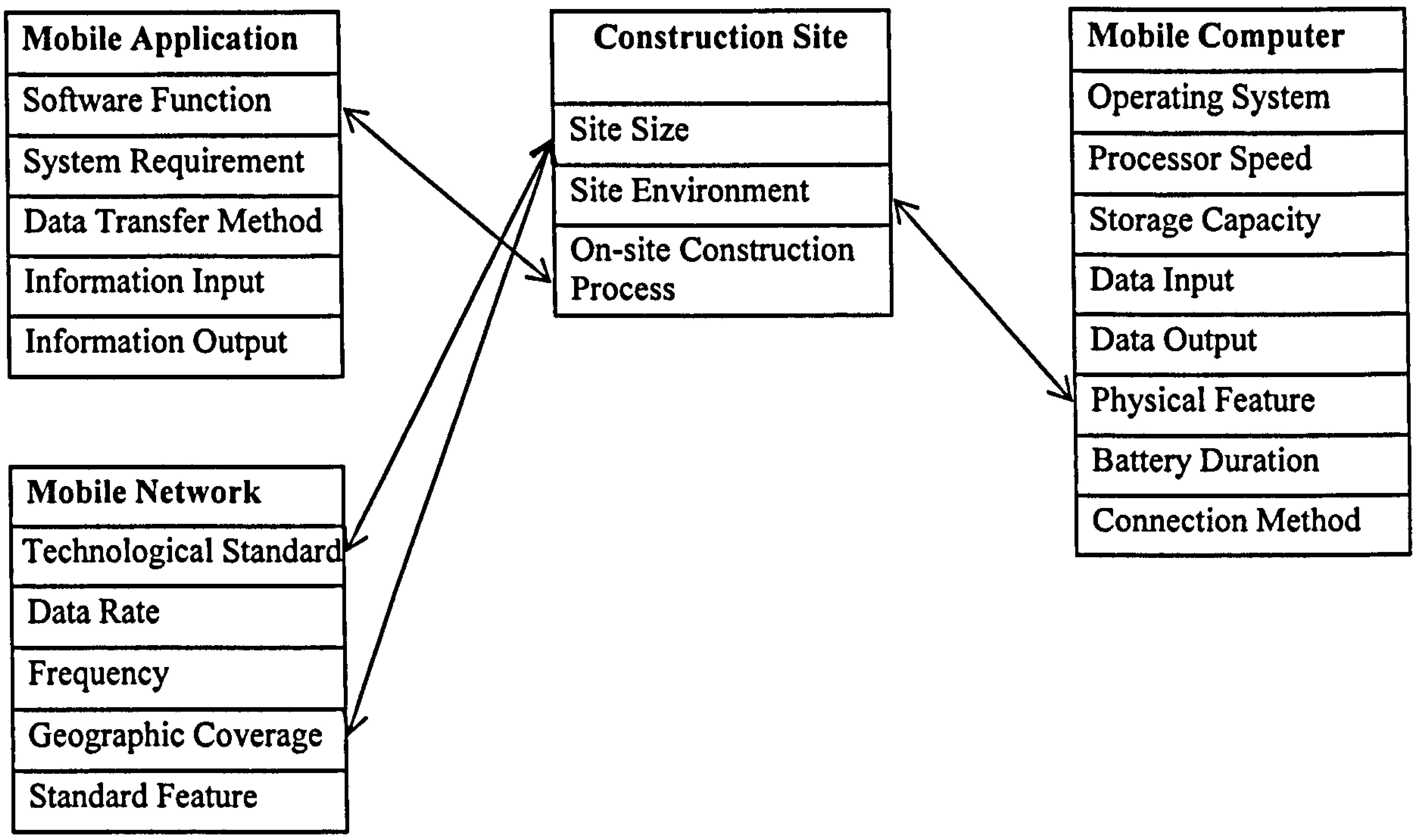


Figure 6. 6 Interrelationships between 'Construction Site' and 'Mobile Computing'

6.6 POTENTIAL USE OF THE FRAMEWORK

The identification of sub-factors for each primary factor and the clarification of their interrelationships provide the potential use of the framework in the following areas:

- The framework can be used for the selection of mobile computing strategy. The identified independent factors that have an impact on the use of mobile computing technologies can help project managers or information system designers to describe the main characteristics of the project. The clarification of interrelationships between each two factors can help them to select mobile computing strategies to suit the characteristics of the project. The detailed procedure of using the framework for the selection of mobile computing strategy will be discussed in the next chapter.
- The framework can be used to set up the knowledge base for the development of a rule-based expert system that aims to select mobile computing technologies. Identified interrelationships between two sub-factors can be further translated to a

list of IF/THEN structure rules that represent the domain knowledge of the implementation of mobile computing in managing construction site information. As a simple example, the link between the sub-factor 'on-site time' and the sub-factor 'battery duration', which indicates that 'the battery duration should persist for a long enough period of time in which a user is outdoors on work sites', can be translated to the rule of 'IF the duration time users spend outdoors on work sites is *n* hours, THEN the battery persisting time of a mobile computer is more than *n* hours.'

- The framework can provide guidance for requirements capture before the design of a new mobile computing system. The aim of developing a new mobile computing system must be to produce something that meets the needs of the people who will be using it. The identified relationships in the framework between the user and mobile computing can help system designers to capture users' requirements such as their information needs, the software functions they expect, the network coverage they need, and the Human Computer Interaction (HCI) design that can facilitate user's information inputs and outputs. The links between construction information and mobile computing identify the requirements that a mobile computer must have enough capability to input, output and process the required information, wireless networks must have sufficient bandwidth to transfer the information at a satisfactory speed, and mobile applications should have rich software functions to manage the needed information. The links between the construction site and mobile computing in the framework require that the new mobile computing system can achieve the design goals in a specific construction environment.

6.7 SUMMARY

Following an explanation of how the results obtained from the literature review, case studies and the survey have been used in the development of the framework, this chapter provided a detailed explanation with the identification of sub-factors for each primary factor and the clarification of their interrelationships. This chapter then discussed the potential uses of the developed framework in three areas, and one of the three applications will be discussed in great depth in the next chapter.

CHAPTER 7

APPLICATION OF THE DEVELOPED FRAMEWORK

7.1 INTRODUCTION

This chapter presents the procedure, using the developed framework, for the selection of a mobile computing strategy. It then illustrates this selection procedure through a real construction scenario.

7.2 THE SELECTION OF A MOBILE COMPUTING STRATEGY

One of the applications for the developed framework is to select a mobile computing strategy for managing on-site construction information. The aim of the selection procedure for a mobile computing strategy is to select the appropriate mobile computing strategy and technologies to suit the specific characteristics of a construction project. This selection procedure has three major steps: the definition of on-site information management objectives, the identification of mobile computing strategy, and the selection of appropriate mobile computing technologies. This selection procedure should be conducted at the construction planning stage before the start of work on sites.

7.2.1 DEFINITION OF ON-SITE INFORMATION MANAGEMENT OBJECTIVES

The current situation of information management on construction sites can be summarised from two aspects: the separation between site offices and construction work sites, and the separation between design and construction. With the advance of Information Technology, current IT support has extended to construction site offices, but construction projects typically take place on work sites where construction personnel have difficulty in gaining access to conventional information systems. The current situation has resulted in the separation of information flows between site offices and work sites. The key difficulty for information communication between designers and construction personnel is the distance between production points (construction work sites) and design offices. The principles of the integration of design and construction require effective communication at the task level between work points and the design team. The need for the integration of construction sites and the integrated design and construction has been discussed in great detail in Chapter 2.3.3.3.

The emergence of mobile computing has the potential to enlarge the boundary of information systems from site offices to actual work sites and ensure real time data flow to and from construction work sites. Therefore, there are potentially two main objectives of using mobile computing on construction sites: the integration of information management between site offices and construction work sites, and the integration of design and construction. The integration of site offices and construction work sites aims to extend IT support from site offices to construction work sites, which allows construction personnel to access computing whenever they need and wherever they are on work sites. The improved communication between fieldworkers at the point of sites and off-site collaborators in building design is one of the key principles for integrated design and construction and a key factor for the success of a 'concurrent engineering' strategy in the construction industry.

In order to achieve the two objectives, areas that can be improved by implementing mobile computing technologies such as PDAs, Tablet PCs, Bar-coding, Wireless Sensors, GPRS/GSM/3G, Wireless LAN, and Mobile Application Software, can be identified by taking account of the following guides:

- Information management activities where information is retrieved at construction work sites by paper.
- Information management activities where information is processed on paper such as view, amend, edit, check, update, collect, and record.
- Information management activities where information is transferred from construction work sites by paper.
- Information management activities that could be fully automated if electronic data is available.
- Information management activities involving communication with other personnel using traditional methods (e.g. by telephone, fax, or post).
- Information management activities involving the information exchange from personnel to personnel, personnel to information system, personnel to document

storage place, work site to site office, site office to headquarter, which can be replaced by mobile computing.

Some potential areas that can benefit from the use of mobile computing have been identified in other research projects, which were introduced in Chapter 3.9.4. The improvement of the highlighted potential areas by using mobile computing technologies can help the project team to achieve the desired objectives of the integration of construction sites and the integrated design and construction. The output of this stage is the potential areas that can be improved through the use of mobile computing technologies for the achievement of desired objectives.

7.2.2 IDENTIFICATION OF MOBILE COMPUTING STRATEGY

The second stage aims to assist users to select an appropriate mobile computing strategy that can achieve the defined objectives in the first stage. Figure 7.1 is the pre-defined "square" that identifies the current situation, the desired objectives and different mobile computing strategies and maps out the different ways that on-site information management can be improved from current situations to desired objectives. Additionally, in response to the features of different information management practices and various construction situations, the general "square" can be modified in terms of adding or reducing mobile computing strategies based on a user's own circumstance.

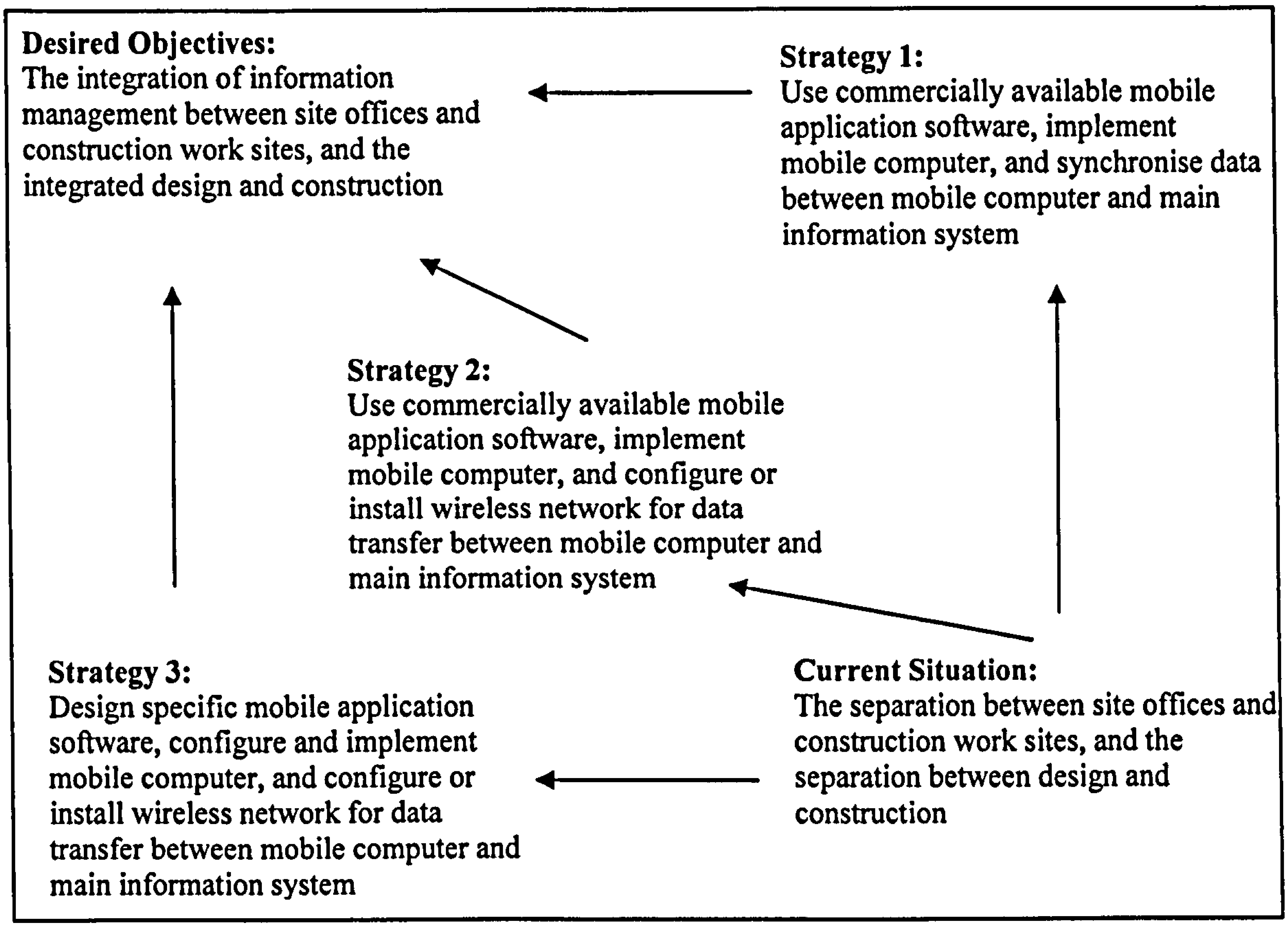


Figure 7. 1 The Mobile Computing Strategy Matrices

Figure 7.1 shows three paths in terms of the mobile computing strategies that can improve present information management to desired objectives on construction sites. In this figure, the current situations of on-site information management are summarised as the separation between site offices and construction work sites and the separation between design and construction. The desired objectives of the integration between site offices and work sites and the integration of design and construction require improved information management on construction sites through the use of mobile computing in suitable areas.

In order to achieve the desired objectives, the three mobile computing strategies represent different extents of implementing mobile computing to manage information on construction sites. The first mobile computing strategy includes the use of commercially available mobile computers and mobile application software, and the synchronisation of data between mobile computers and site-office-based computers via wired connections (USB or Ethernet) or short range wireless connections (Bluetooth or IrDA). In the first strategy, long distance wireless networks are not used and mobile users need to synchronise data in site offices before and after site visits. This means that real-time information retrieval and transfer on construction work sites (outside site offices) are not supported by this mobile computing strategy. However, this strategy is the simplest way to apply mobile computing on construction sites and does not need sophisticated technical configuration and support. This strategy can be widely used in on-site information management and integrated into current organisational information systems using existing commercially available mobile computers and application software. The first strategy cannot fully achieve the two desired integration targets because of the lack of real-time data communication, but it supports users in the access to computing on construction work sites, which is an alternative way to integrate information management on work sites with the IT support in site offices.

Compared with the first strategy, the second mobile computing strategy provides the coverage of wireless networks (WLAN or WWAN) on construction sites, and then mobile users can retrieve or transfer information on construction work sites without coming back to site offices and synchronising data with fixed computers. This strategy supports real-time information communication so that mobile users can receive any revised information instantly on construction work sites and any collected information on work sites can be immediately reflected on organisational information systems. Because of the involvement of wireless networks, the second strategy needs more complex designs and configurations including the selection of wireless networks, the connection between mobile computers and wireless networks, and the integration of mobile computing systems into existing organisational information systems. With the connection to wireless networks and the support of real-time data communication, the second mobile computing strategy can fully achieve the integration between site offices and work sites. However, the desired objective of integrated design and construction cannot be fully achieved because the commercially available mobile computing products with limited types, functions and services cannot fully meet the specific requirements of the integrated design and construction for a particular project.

The third strategy is the full extent of implementing mobile computing on construction sites. This strategy refers to the design of a whole mobile computing system including the selection of appropriate mobile computers, the configuration and set up of wireless networks, and the design of specific mobile application software, according to the particular construction situation and users' requirements. This strategy needs system designers to understand users' requirements for on-site information management, analyse on-site construction processes that can be improved by mobile computing, and design the mobile application software to meet the needs of information management. Because the design of mobile computing systems can only be done by computer professionals through long term software design life-cycle, the third strategy of designing mobile computing systems is especially expensive and time consuming. With the support of the whole mobile computing systems and the specific design requirements, the third mobile computing strategy can completely achieve the desired objectives of the integration between site offices and work sites and integrated design and construction.

7.2.3 SELECTION OF APPROPRIATE MOBILE COMPUTING TECHNOLOGY

The final stage of this selection procedure focuses on the selection of appropriate mobile computing technologies for a specific mobile computing strategy. For each mobile computing strategy identified in the last stage, the appropriate mobile computing technologies including mobile computers, wireless networks and mobile application software, will be selected based on the developed framework of mobile computing in on-site construction information management. Restrictions and interrelationships that may facilitate or inhibit the implementation of mobile computing in managing on-site construction information will also be identified. This can enable an organisation to develop specific plans to implement the selected mobile computing technology relating to their mobile computing strategy.

Figure 7.2 shows the process of selecting mobile computing technologies for the first mobile computing strategy identified in Figure 7.1. This selection process is based on the developed framework of using mobile computing for construction site information management, which has been described in Section 5.

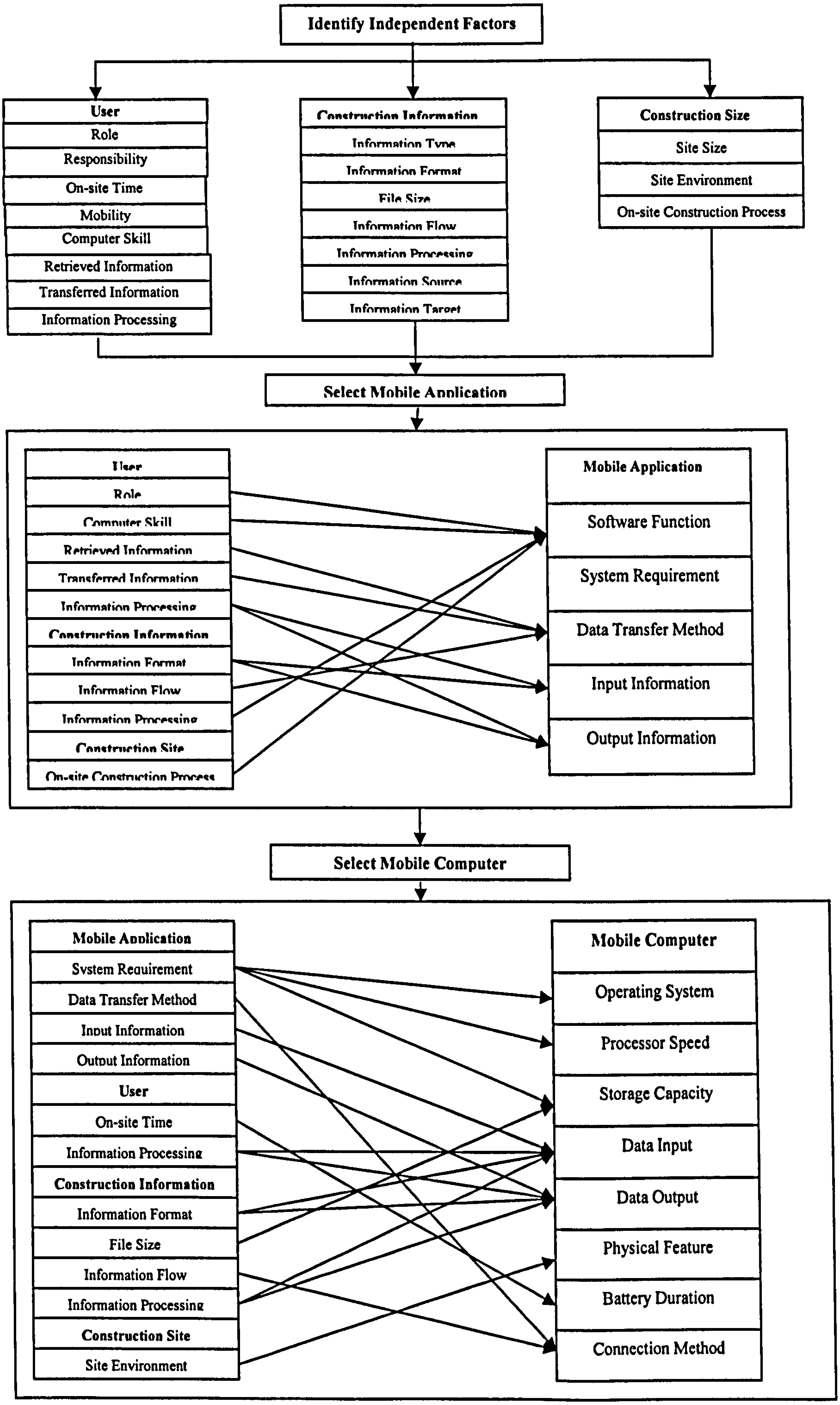


Figure 7. 2 The selection of mobile computing technologies

Because the first mobile computing strategy does not concern the selection of wireless networks, the process of selecting mobile computing technologies consists of three steps: the identification of independent factors, the selection of mobile applications and the selection of mobile computers. Because the independent factors including 'user', 'construction information' and 'construction site', describe the specific construction environment at which mobile computing systems will be implemented for on-site information management, all sub-factors of each primary factor should be specified and identified in order to clarify the users who use the system, their information management requirements, the information that needs to be transferred, the construction processes that the mobile computing system is designed to support, and the construction environment where the system works.

The second step is to select mobile applications based on the interrelationships between independent and dependent factors that have been identified in the developed framework. The selected mobile applications should fulfil mobile users' information management requirements, have enough functions to process required information, and support the information communication of the specific on-site construction process. The data transfer methods of the selected mobile application should allow users to retrieve information on work sites or transfer information from work sites and should permit users to use the most efficient and convenient transfer method according to different circumstances. The selected mobile application should have well designed Human Computer Interaction (HCI) methods that can permit users to input essential construction information and can output required information via various HCI designs such as touch screen, keyboard, voice identification, handwriting identification and software interface design.

The third step is to select appropriate mobile computers according to the identified factors and the selected mobile application. The proposed mobile computers should be compatible with the selected mobile application and have essential capability including processor speed and storage capacity to run it. Its connection methods, such as USB, Bluetooth, IrDA, WWAN and WLAN connections, have to meet the connection standards of the selected mobile application and can transfer information between mobile computers and organisational information systems. According to the site environment, the proposed mobile computers may have specific physical features such as rugged screen, water and dust protection and crash resistant, and should have long-time battery duration to support users' information management activities on work sites. Methods of data input and output for a mobile computer concern the hardware perspective of Human Computer Interaction (HCI) and should ensure that users can process information on construction work sites efficiently and effectively. Mobile computer output and input methods should be able to deal with the various formats of construction information, such as the display of large scale construction drawings, the transfer of verbal-based information, and the various data input equipment selected by users.

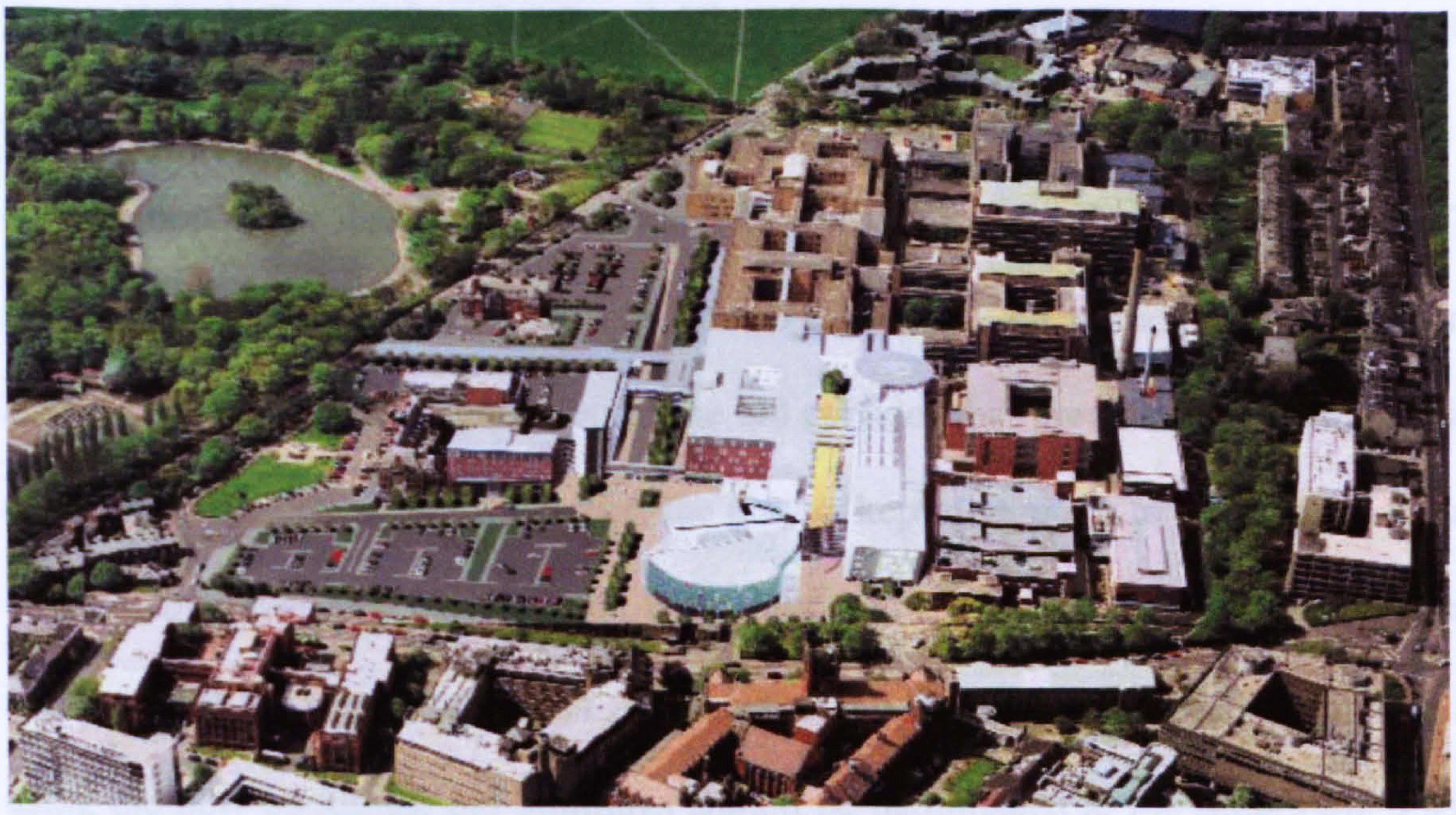
7.3 AN ILLUSTRATIVE SCENARIO

As discussed in the methodology section (Section 4.3.3), the developed framework should be evaluated and validated in order to compare it with realisations of the reality. This section aims to use this framework with an illustrative construction scenario. A case study was used to apply the developed framework in a real construction situation and the details of conducting the case study can be found in Section 4.6.5.

7.3.1 CONSTRUCTION PROJECT BACKGROUND

The selected construction site is the Royal Victoria Infirmary (RVI) project that is included in the project "Transforming the Newcastle Hospitals". The £300 million project was signed between The Newcastle upon Tyne Hospitals Trust and Healthcare Support (Newcastle) (HSN), a consortium led by Equion and supported by partners, Laing O'Rourke and Interservefm. The scheme will move all acute hospital services from the Newcastle General Hospital site and re-provide them in state of the art facilities at the Royal Victoria Infirmary (RVI) and the Freeman Hospital. The contract is for 38 years, with an eight year construction programme followed by 30 years of operation.

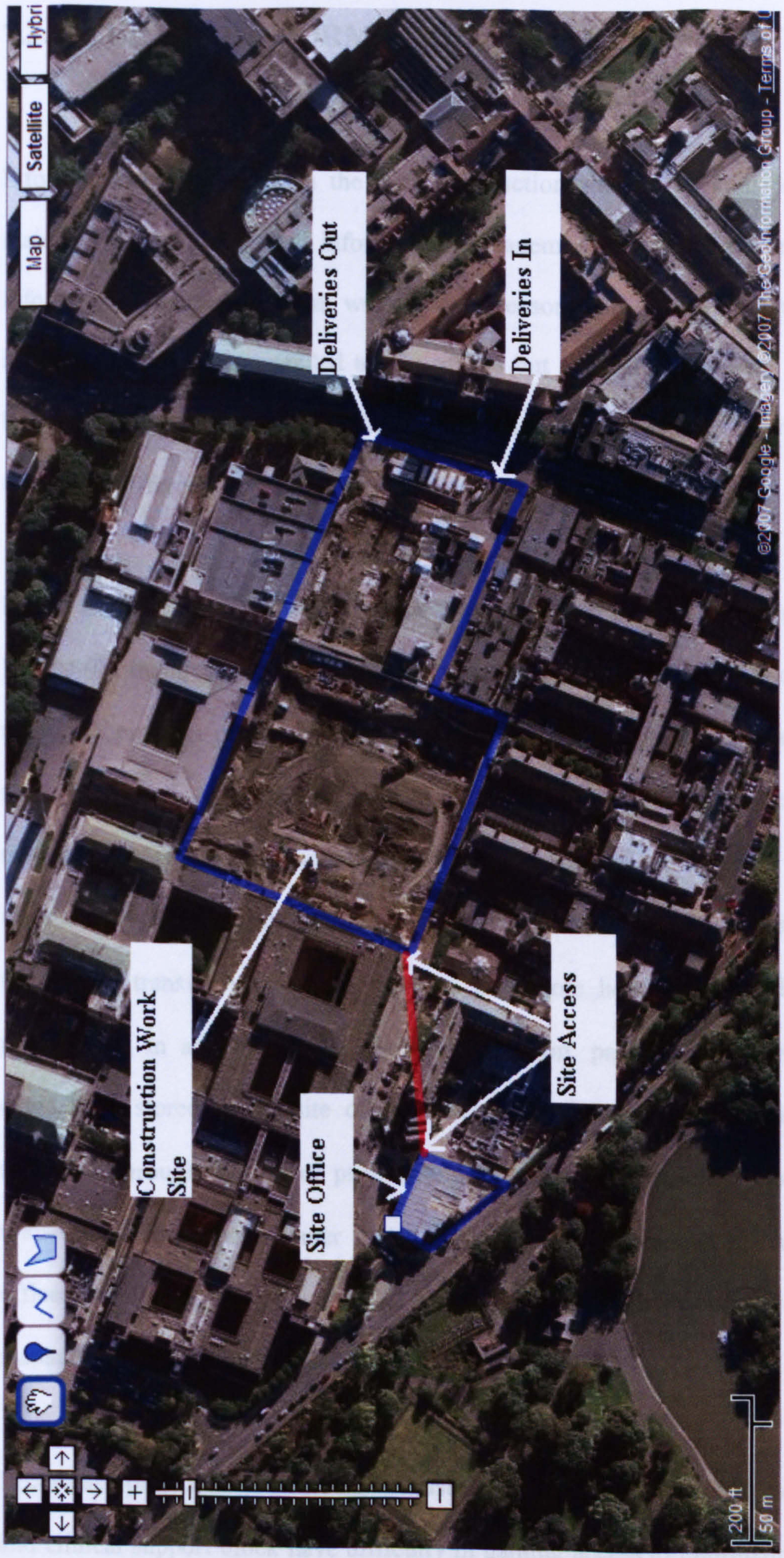
The development at the Royal Victoria Infirmary (RVI) project includes 60,000m^2 construction area and comprises 2 main blocks: the clinical block and clinical support block. Picture 7.1 is an aerial view of Royal Victoria Infirmary (RVI) upon completion. The clinical block comprises three main elements including the children's wing, the 'high tech' block and the ward block, all of which are joined together by an impressive 6 storey atrium. The clinical support block will house medical consultants and support staff as well as a new Education Centre. Located around the existing building, it will form the administrative hub of the hospital and is linked to the clinical block with two bridges. Picture 7.2 is the 3-D view of the new entrance for the Royal Victoria Infirmary (RVI).



Picture 7.1: Aerial view of Royal Victoria Infirmary (RVI) upon completion

Picture 7.2: 3-D View of the new entrance for the Royal Victoria Infirmary

The major challenge that the Royal Victoria Infirmary (RVI) project faces is that continuity of hospital services and engineering services should be maintained during the construction of the new building, which is bigger than many other whole hospitals. The first stage of the project involved moving hospital departments into temporary accommodation and the demolition of the old corridor that previously linked both sides of the hospital. During the first stage, the project kept disruption to a minimum through collaborative working between the contractor and the hospital. A further challenge ahead for the project construction is that when the hospital has to start occupying and using the new buildings, old buildings should be demolished at the same time. Picture 7.3 is the satellite view of the construction site, where the site office and the construction work site are marked out with blue lines. This satellite picture clearly shows that the project construction site is surrounded by the old hospital buildings.



Picture 7.3: Satellite view of the project construction site (From Google Maps)

7.3.2 CURRENT INFORMATION MANAGEMENT ON THE CONSTRUCTION SITE

Information management on the RVI construction site can be considered from two major aspects: IT-supported information management in site offices and paper-based information management on work sites. Reasons for this are that IT-supported information flows are extended to site offices but end before reaching work sites and because the effectiveness and efficiency of managing information in the two areas is especially different.

In the site offices, the RVI project team is supported by desktop computers, project Intranet/Extranet, and Internet. Project team members can use Outlook software to manage their own personal information such as email, contacts, calendar, and to-do tasks. They can also use professional software such as CAD applications, project management applications and collaborative applications, to manage project-related information. By connected networks, project members in site offices can directly retrieve or transfer information from or to remote headquarters and other project participants. In addition to the digital information, paper-based information is also extensively stored in the site offices, such as drawings, contracts, documents, and archives. Through the use of printers and scanners, information can be conveniently transformed between computer systems and papers. Information management in site offices is fully support by various IT tools which have broadly improved information management efficiency.

In contrast, project team members at construction work sites including the clinical block and clinical support block have difficulty in gaining access to information systems that can only be accessed while they stay in the site offices. Therefore, digital information flows are interrupted before reaching the work sites where actual construction activities are taking place. In order to retrieve information on work sites, project team members have to take vast paper-based construction documents such as drawings, specifications, and design clarifications when they stay on construction work sites. Additionally, construction personnel have to maintain paper-based records when they collect information on work sites. Since the construction area of this project is 60,000m^2 and it consists of two high buildings, the current information management situation leads to inconvenience and inefficiency of managing information on work sites, because construction personnel have to transform digital information into paper-based information via printers before their site visits and input the collected information back into computer systems after their site visits.

7.3.3 SELECTING MOBILE COMPUTING STRATEGY

Based on the developed framework, Chapter 7.2 provided a three-step procedure for selecting mobile computing technology for construction site information management. This section will demonstrate how to select mobile computing technologies for the specific RVI project according to the selection procedure and the developed framework.

7.3.3.1 On-site Information Management Objective

The key objective of using mobile computing on RVI construction sites is the integration of information management between site offices and construction work sites. This target indicates the extension of the IT boundary from site offices to actual work sites and the overcoming of the obstacle of digital information flow between site offices and work sites.

The integration of on-site information management with project information systems ensures that project team members can have real time information retrieval and transfer on construction work sites. With the support of mobile computing technologies, they can use mobile computers, such as Pocket PCs or Tablet PCs, with the connection to wireless networks to access project information or personal information stored in remote computers and servers that are normally fixed in site offices. Therefore, construction information can be retrieved, processed, collected and transferred digitally by project team members on work sites and automatic information management activities are possible.

7.3.3.2 Identifying Mobile Computing Strategy

In order to achieve the desired objective, it is necessary to select an appropriate mobile computing strategy that can assist users to choose related mobile computing technologies. According to the desired objective of the integration between site offices and work sites and the consideration of mobile computing strategies at different levels, the second strategy in Figure 7.1 can fulfil the requirements of improved on-site information management.

The second mobile computing strategy consists of the use of commercially available mobile computers, the selection of related application software and the configuration of wireless networks. This strategy supports real-time information communication that allows mobile users to be able to receive any revised information instantly on construction work sites and any collected data to be immediately transferred to project information systems.

One important reason for selecting the second mobile computing strategy rather than the first strategy is because the first strategy that synchronises construction information between mobile computers and fixed desktop computers in site offices cannot provide the full benefits of on-site information management that mobile computing can offer in this construction project. According to the site layout in Picture 7.3, the site office is located approximately 100m away from the actual work sites and the construction area of this project is 60,000m^2 including two high building blocks. If mobile users cannot have the support of wireless networks, they have to travel between site offices and work sites in order to synchronise data between mobile computers and desktop computers, which leads to inefficient information retrieval and transfer.

7.3.3.3 Identifying the Three Independent Factors

After the identification of mobile computing strategy, mobile computing technologies including mobile computers, wireless networks and mobile application software, can be selected based on the third step of the selection procedure. Restrictions and interrelationships that may facilitate or inhibit the implementation of mobile computing can be also recognised and determined.

The first step is to identify the three independent factors: 'construction site', 'user' and 'construction information'. As shown in Picture 7.3 and introduced in Section 7.3.1, the construction site includes two main high building blocks, of which the total construction areas are 60,000m^2, and the site office is located approximately 100m away from the actual work sites. The site environment of the RVI project is a typical construction site environment. Construction activities are conducted outdoors, the weather conditions are the typical British weather with sun and rain at intervals, and the working conditions are the standard construction environment with dust, moisture, and noise. The current ongoing construction processes vary depending upon the different construction phases. Internal fit-out is ongoing for the most advanced phase, whereas superstructure is ongoing in the least advanced phase. In between there is a whole range of activities including external envelope, brickwork, M&E (Mechanic and Electronic) installation, and screeding. Picture 7.4 is an aerial view of the construction site for the Royal Victoria Infirmary (RVI) project.

Picture 7.4: Aerial view of the construction site for Royal Victoria Infirmary (RVI) project

The independent factor 'user' refers to construction personnel who use mobile computing technologies to fulfil their information management requirements on the

RVI construction site. This case study has identified a number of construction personnel consisting of the business procedures manager, mechanical project engineer, senior procurement manager, and project manager. The scenario will choose the business procedures manager and mechanical project engineer as the illustrative examples to demonstrate what and how mobile computing technologies can assist them to manage information on construction sites. Table 7.1 shows the detailed sub-factors of the primary factor 'user' for the two illustrative examples: business procedures manager and mechanical project engineer.

The business procedures manager is in charge of the contractor's work and is consulted on engineering aspects of construction tasks. He needs to visit nearly all site areas and spends around 15 hours per week on construction work sites. Construction information that the business procedures manager needs on work sites include drawings, construction methods, sub-contractor information, quality information, and safety information. These kinds of information are received from other construction personnel, computer systems or documents stored in site offices. The business procedures manager normally takes paper-based drawings or documents to construction work sites in order to support his on-site information needs. Construction information collected by the business procedures manager on work sites includes construction methods, sub-contractor information, and quality information. All collected information is recorded on paper and inputted into computer systems when he is back in the site office.

User Type / User Profile	Business Procedures Manager	Mechanical Project Engineer
Role	Business Procedures Manager	Mechanical Project Engineer
Responsibility	Consultation and supervision on engineering aspects of the construction tasks.	Design and installation management.
Onsite Time	10 – 15 hours per week on construction work sites.	More than 20 hours per week on construction work sites.
Mobility	Mobility covers most area of work sites.	Mobility covers most area of work sites.
Computer Skill	Appropriate knowledge on computers, but need extra training on mobile computing technologies.	Appropriate knowledge on computers, but need extra training on mobile computing technologies.
Retrieved Information	Drawings, construction methods, sub-contractor information, quality information, safety information.	Drawings, material information, equipment information, progress information, design clarification, construction methods, sub-contractor information.
Transferred Information	Construction methods, sub-contractor information, quality information,	Drawings, material information equipment information, progress information, design clarification.
Information Processing	View, mark up, update, check, and clarify.	View, edit, draw, mark up, measure, write, update, check, and clarify.

Table 7. 1 Detailed sub-factors of the primary factor of 'user' for the two illustrative examples: business procedures manager and mechanical project engineer

Another identified construction personnel is the mechanical project manager who is in charge of the design and installation management of mechanical works. The mechanical project manager needs to visit nearly all site areas and stays on work sites for more than 20 hours per week. On construction work sites, the business procedures manager needs different types of information such as drawings, material information, equipment information, progress information, design clarification, construction methods, and sub-contractor information. Information is received from other construction personnel, computer systems or documents stored in site office. The mechanical project manager normally takes paper-based drawings or documents to construction work sites in order to support his on-site information needs. Construction information collected on work sites includes drawings, material information, equipment information, progress information, and design clarification. The mechanical project engineer needs more complex information process activities including viewing, editing, marking up, updating, measuring, checking, and clarification. All collected information is recorded on paper and inputted into computer systems when he is back in the site office.

Different construction personnel have varying information needs. According to the information needs of the business procedures manager and the mechanical project engineer, Table 7.2 and Table 7.3 identify the detailed sub-factors of 'construction information' for the two potential users. All this construction information is to be managed by mobile computers on the construction work site, and retrieved and transferred through wireless networks between mobile computers used on work sites and computer systems fixed in site offices.

Information Type	Information Format	File Size	Information flow	Information Processing	Information Source	Information Target
Drawing	Text, Graphic	Large	Retrieve	Viewing, Marking up	People, Computer System, Document Storage	N/A
Construction and Engineering Methods	Text, Graphic, Image, Verbal	Large	Retrieve Transfer	Viewing, Checking, Updating	People, Computer System, Document Storage	Computer System, Document Storage
Sub-contractor Information	Text, Graphic, Form, Verbal	Medium	Retrieve Transfer	Viewing, Writing, Checking, Updating	People, Computer System, Document Storage	Computer System, Document Storage
Labour Information	Text, Form	Medium	Retrieve	Viewing, Checking, Updating	People, Computer System, Document Storage	N/A
Quality Control Information	Text, Form, Verbal	Medium	Retrieve Transfer	Viewing, Checking	People, Computer System, Document Storage	Computer System, Document Storage
Safety Information	Text, Form, Verbal	Medium	Retrieve	Viewing, Checking	People, Computer System, Document Storage	N/A

Table 7. 2 Construction information needs of the business procedures manager

Information Type	Information Format	File Size	Information flow	Information Processing	Information Source	Information Target
Drawing	Text, Graphic	Large	Retrieve Transfer	Viewing, Editing, Drawing, Marking up, Measuring	People, Computer System, Document Storage	People, Computer System, Document Storage
Material Management Information	Text, Form, Verbal	Medium	Retrieve Transfer	Viewing, Writing, Checking, Updating	People, Computer System	People, Computer System
Equipment Management Information	Text, Form, Verbal	Medium	Retrieve, Transfer	Viewing, Writing, Checking, Updating	People, Computer System	People, Computer System
Schedule and Progress Information	Text, Graphic, Verbal	Medium	Retrieve Transfer	Viewing, Writing, Checking, Updating	People, Computer System	People, Computer System
Design Clarification	Text, Graphic, Verbal	Medium	Retrieve Transfer	Viewing, Checking, Updating, Clarifying	People, Computer System, Document Storage	Computer System, Document Storage
Construction and Engineering Methods	Text, Graphic, Image, Verbal	Large	Retrieve	Viewing, Checking	People, Computer System, Document Storage	N/A
Sub-contractor Information	Text, Graphic, Form, Verbal	Medium	Retrieve	Viewing, Checking, Updating	People, Computer System, Document Storage	N/A
Labour Information	Text, Form	Medium	Retrieve	Viewing, Checking, Updating	People, Computer System, Document Storage	N/A
Quality Control Information	Text, Form, Verbal	Medium	Retrieve	Viewing, Checking, Updating	People, Computer System, Document Storage	N/A
Safety Information	Text, Form, Verbal	Medium	Retrieve	Viewing, Checking, Updating	People, Computer System, Document Storage	N/A

Table 7. 3 Construction information needs of the mechanical project engineer

7.3.3.4 Selecting Mobile Computing Technology

The identification of three independent factors and their sub-factors determines the users who use the mobile computing system, the construction information that the mobile computing system needs to deal with, and the construction environment where the system works. Therefore, the following steps aim to select appropriate mobile application software, mobile computers and wireless networks, which comprise the mobile computing system for mobile users to manage information on construction sites.

The first step is to select mobile application software. Based on their roles in the construction project, the business procedures manager and mechanical project engineer have general and specific requirements of mobile software functions. The software functions should generally support them to process the required construction information on work sites. Because both of them need to retrieve and review drawings, mobile AutoCAD software should be selected to support users to manage AutoCAD-based drawings. Information processing activities include viewing, amending, editing and measuring AutoCAD drawings on work sites, which should be supported by the selected mobile AutoCAD software. There are several commercially available mobile AutoCAD software (see Section 6.3.3), which have sufficient software functions and well-designed Human Computer Interaction (HCI) methods in order to increase the efficiency and convenience of data input/output for mobile users. PowerCAD SiteMaster can be selected as the mobile AutoCAD software application for both the business procedures manager and the mechanical project engineer.

In addition to the mobile AutoCAD software, both mobile users need to manage other construction information on work sites, such as their own personal information, construction methods, design clarification, sub-contractor information, labour information and quality information. Therefore, they need other mobile application software to support their information management requirements. For their personal information management, the mobile Outlook allows users to check emails, update calendars, and collaborate with other project members. In the RVI project, project information, such as material information, construction methods, sub-contractor information and quality information, are normally stored in the database of computer systems, which can be accessed by project members through the project Intranet. Therefore, the business procedures manager and the mechanical project engineer can use mobile Internet Explorer that provides the access to project Intranet Web sites and assists users to retrieve information when they are in motion. Other mobile application software that can be selected to help mobile users to manage on-site information consists of Mobile Adobe Reader for the display of PDF files, Mobile Word for the management of Word files on sites, and mobile picture viewer for the display and editing of pictures.

After the identification of required mobile application software, the second step is to select mobile computers that can be used by the two mobile users to run the selected mobile software. The PowerCAD SiteMaster as the selected mobile CAD software can run on Windows Mobile based Pocket PCs and Windows XP based Tablet PCs with sufficient system requirements. The PowerCAD SiteMaster supports a number of data transfer methods including Bluetooth, USB synchronisation, Infrared, and Wireless Local Area Networks, which should be supported by the selected mobile computers. For displaying the CAD drawings, the screen of the selected mobile computer should have sufficient screen size and enough screen resolution. Because the selected mobile computers need to run other mobile applications and deal with various types of information formats, mobile computers should have multi-data-input equipment including the keyboard input for text, touch screen input for graphics, and microphone for voice transfer. The battery life should support the on-site time for the two users. Because the RVI site environment is outdoors, dust, moisture and high building blocks exist, the selected mobile computers are recommended to have rugged screen, water and dust protection, and be crush resistant to confront the poor site environment.

For the business procedures manager, the pocket PC (HP hx2790), see Picture 7.5, has adequate capability to run the required mobile application software and can fulfil this user's information management requirements. The HP hx2790 pocket PC runs on the Microsoft Windows Mobile operating system that supports the selected mobile application software including the PowerCAD SiteMaster, Internet Explore Mobile, Word Mobile, Task Manager, and Picture Viewer. It has multi data input/output equipment, such as the screen, microphone, speakers, touch screen input, and navigation button. The business procedures manager can connect to the project computer systems through the connectivity of Wireless Local Area Network provided by the selected pocket PC in order to retrieve and transfer required construction information at the places where he conducts the actual construction activities.

Picture 7.5: An example of the select pocket PC

Because the mechanical project engineer has to carry out more complex information management activities and needs more detailed display of AutoCAD drawings, the rugged Tablet PC (Tronix Duo-Touch), is more suitable for him, see Picture 7.6. The selected Tablet PC has the full computer capability of normal desktop computers, but can be used when the user is in motion. It runs the operating system of Microsoft Windows XP Tablet Edition and other professional application software that can be run on desktop computers. The big screen size and high screen resolution ensure that AutoCAD drawings can be displayed more clearly and amended more easily by users on construction work sites. The Tablet PC has a lot of Human Computer Interaction equipment including the touch screen with stylus, QWERTY keyboard, camera, microphone, and speakers, and supports various network connection methods, such as the Bluetooth, Infrared, Ethernet, Modem, Wireless Local Area Network, and Wireless Wide Area Network. Since the mechanical project engineer always works within a tough construction environment, the rugged and weatherised features including the protection for shock, drop and vibration, shock-mounted hard drive, die-cast magnesium case, and resistance to water and dust, ensure that this Tablet computer can be used by construction personnel in the specific construction environment.

Picture 7.6: An example of the selected rugged Tablet PC

For a wireless network that can provide network support for mobile users to use identified mobile application software and mobile computers it is suggested to select Wireless Local Area Network (IEEE 802.11). Firstly, the IEEE 802.11 wireless network protocol is widely used in the commercial market and supported by most wireless commercial products. Both of the selected mobile applications and mobile computers fully support the IEEE 802.11 protocol. Secondly, the digital construction information files that need to be transferred through a wireless network to construction work sites are large and are required to be transferred without delay and lag. The IEEE 802.11 wireless network can provide a bandwidth up to 11Mbps, which is sufficient to transfer large-size files such as drawings, pictures, and voice. Thirdly, the IEEE 802.11 wireless network can provide a transmission range from 30 up to 100 metres and the wireless coverage can be extended by applying more wireless network antennas, each of which can provide coverage to a certain area of the site allowing roaming users to connect to the project computer systems and can divert the wireless signal around obstructions. Finally, computer systems in site offices are supported by Ethernet that can easily be extended to set up the IEEE 802.11 wireless network through the wireless routers. Therefore, the mobile computing system can be smoothly integrated into the current computer systems without complex configurations.

7.4 DISCUSSION

This real construction scenario as an illustrative example demonstrates the application of the developed framework to select a mobile computing strategy to suit the characteristics of a specific construction situation. Because of the potential of mobile computing technology, the desired objectives of implementing mobile computing in construction site information management can generally be summarised from two aspects: the integration between site offices and work sites, and the integration of design and construction. The different mobile computing strategies in Figure 7.1 can achieve the desired integration at different levels depending on the user's requirements. For the selected strategy, suitable mobile computing technologies can be selected by users based on the developed framework.

The potential areas that can benefit from the implementation of mobile computing should also be identified in order to achieve the desired integration objectives. Some potential areas identified in other research projects (ARUP, 2003; Saidi et al., 2002) have been introduced in Chapter 3.9.4, and Chapter 7.2.1 also provided a list of guides that can help users to identify relevant areas based on their own circumstances.

Because of the limitation of time and budget, tests for the selected mobile computing technologies in real construction circumstances have not been conducted in this research. However, the evaluation of the selected mobile computing technologies in real construction sites can provide the determination of whether the structure of the framework and the relevant procedure for selecting mobile computing strategy are reasonable and whether the framework and the selection procedure reflect the realisations of the real construction situations. Further work is needed to test the selected mobile computing technologies on real construction sites.

7.5 SUMMARY

The procedure of selecting mobile computing strategy, as one of the applications of the developed framework discussed in Chapter 6, had three major steps: the definition of on-site information management objectives, the identification of mobile computing strategy, and the selection of appropriate mobile computing technologies. Based on the real construction project, this procedure has been demonstrated in an illustrative scenario. Further works are needed to test mobile computing technologies on real construction sites.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 INTRODUCTION

This chapter concludes this thesis, which has described the development of a framework for the implementation of mobile computing in managing information on construction sites. It provides a summary of the work undertaken, realisation of the research aims and objectives, benefits of the framework, contribution to knowledge, limitations of the research, recommendations for further work and closing comments.

8.2 GENERAL SUMMARY

The research reported in this thesis was based on the need to improve the efficiency and effectiveness of construction information management with regard to the problems associated with the fragmentation in the construction industry. It focused on the implementation of mobile computing technology, which was seen as the potentially effective key to the improvement of information management on construction sites. This research developed a framework to explore how mobile computing can be used for the information management on construction sites, and provided a procedure for selecting a mobile computing strategy to suit the characteristics of a specific construction project. The specific tasks undertaken for the development of the framework, with respect to the objectives of this research, are summarised below.

The research adopted the view point that the definition of 'information' should consider the differences in phenomena at different levels of the context structure. Therefore, the operational definition of 'information' for this research accepted the definitional hierarchy that was based on differences in level of scope and complexity. 'Information' in this research was defined from four aspects: information as a resource or commodity, information as data in environment, information as a representation of knowledge, and information as a constitutive force in society. Correspondingly, the operational definition for 'information management' in this research was defined at four levels: information retrieval, information systems, information contexts, and information environment.

According to the definition of 'information' in differences in level of scope and complexity, construction information can be categorised from different perspectives and at various levels. At the organisational level, construction information includes technical information, commercial information, and management and control information. Regarding the whole construction life-cycle, information required by construction processes includes the nature and wishes of the client (client requirements), the nature and desires of proposed users of the facility (user requirements), the nature of the site on which the facility is to be built and the immediate environment (site information), and information on the regulations that apply to that facility. A construction site is an information intensive environment and on-site information includes requests for information, material information, equipment information, cost, schedule and means and methods, jobsite records, submittals, safety, QC/QA, and future trends. At the construction individual level, information needs are often inextricably linked to the management responsibilities of each member of the project team.

Because of the intensity and diversity of construction information, the efficiency of information management is crucial to the construction industry and has been recognised as an important competitive advantage to construction companies. Research issues in the area of construction information management contributed many useful experiences in developing information systems, bringing forward new thinking on managing information, and providing solutions from various perspectives. The main research issues included: the information flow modelling, document management, product modelling, Groupware Systems, knowledge management systems, and web-based project management systems. However, current construction information management has several existing problems which include: paper-based information exchange, the structured data of functional departments only for their own needs, paper-based information searching and transfer, inefficient interfaces between departmental systems, and the limited impact of IT investment. The separation between site offices and construction work sites and the separation between design and construction have especially restrained the adoption of a greater integration strategy in the construction industry. The principles of concurrent engineering require effective communication at the task level between the work point and the design team. Current information communication methods on construction sites prevent effective information access at construction work sites and improvement of communication between construction and design. The emergence of mobile computing has the potential to enlarge the boundary of IT support from site offices to actual work sites and improve information communication between fieldworkers and the design team, which is the key factor for the integration of design and construction.

Mobile computing consists of three main components: mobile computer, wireless network and mobile application. Mobile computers include the smart-phone, pocket PC, pocket PC phone, Tablet PC, and other mobile computer accessories. Based on their features, wireless networks can be generally classified into four groups: Wireless Wide Area Network (WWAN), Wireless Local Area Network (WLAN), Wireless Personal Area Network (WPAN), and satellite communication. The types of mobile application software include business application software, utility software, entertainment software, and professional applications. In the construction industry, mobile application software includes Mobile CAD, Mobile Data Capture software, and Mobile Project Management software.

Research in the area of Mobile Computing in Construction (MCC) normally focuses on detailed aspects of mobile computing technologies or developing mobile computing systems for single or several construction processes. Research focusing on mobile computing technologies and their implementations includes the areas of context sensitive, speech recognition, IP telephony, wearable computer, Bar-coding, wireless sensor, mobile Ad-Hoc Network, and Ubiquitous Computing. There are several mobile computing systems that aim to improve some construction processes. These systems include data collection systems, mobile construction management systems, on-site problem solving systems, construction site inspection systems, mobile operations support systems, and mobile construction collaboration systems. When a new information technology overtakes older technical solutions, the new technology should become more consistent and reliable. Research that targets the above questions includes the evaluation of mobile computers on construction work sites, examinations of on-site wireless networks, estimations of the whole mobile computing system, construction process comparisons, and the practices of mobile computing in a real construction situation. Mobile computing technologies have been recognised as having great potential in the construction industry and are already being rapidly applied in various types of construction fieldwork. Construction tasks that are suited for mobile computers include the tasks that require access to large amounts of text information, that require viewing a small detail of a document, that require the entry of data into a form, and that require instant transfer of small amounts of information. The challenges of using mobile computing in construction include the complexity and cost of mobile application deployment, the lack of focus for user's requirements, the difficulty of integration with existing applications, content adaptation, and the difficulty of selecting mobile computing technologies. Benefits of the implementation of mobile computing in construction include the reduction in construction time and capital cost of construction, the reduction in operation and maintenance costs, the reduction in defects, accidents, and waste, the increase in productivity, and the increase in predictability.

Various research methods and strategies were adopted to achieve the defined objectives of the research. These included the extensive literature review (Chapter 2 and Chapter 3), case studies (Section 4.6.2), web-based survey (Section 4.6.3), the case study for the validation of the framework (Section 4.6.5), researcher participation at conferences to interact with other researchers in similar research areas, and peer reviews of published papers (Appendix 1). The literature reviewed for this research project dates back over several years and the literature materials include academic papers, books, industrial articles, industrial reports, technical specifications, and electronic resources. Because this research was cross-disciplinary, the literature review focused on two major areas: construction information management and mobile computing. In order to answer the question of how construction personnel manage information on construction sites, the first stage of case studies aimed to obtain a general picture of construction sites, to identify on-site construction personnel, to classify their information needs, and to investigate the current state of on-site IT support. In order to answer the question of what is the existing mechanism of information retrieval and transfer on construction sites, a web-based survey was conducted to investigate the information needs of construction personnel and the mechanism of retrieving and transferring information on construction sites. Then, the framework that identified the key factors and their interrelationships was identified to represent how mobile computing can be used on construction sites by construction personnel to manage on-site information. The final research stage selected the case study as the method to demonstrate the procedure for selecting a mobile computing strategy, which was based on the developed framework, through an illustrative example.

Based on the results obtained from the literature review, case studies and the survey, the framework for using mobile computing for construction site information management provided the primary factors, top-level framework, sub-factors, sub-frameworks and interrelationships between factors. There were six primary factors: 'user', 'construction information', 'construction site', 'mobile computer', 'wireless network', and 'mobile application'. Each of these primary factors was further divided into sub-factors that described the detailed features of relevant primary factors. In order to explore links between sub-factors, the top-level framework was broken down into different sub-frameworks, each of which presented the specific links between two primary factors. The potential use of the developed framework could be in the selection of a mobile computing strategy, the creation of the knowledge base for the development of a rule-based expert system, and the provision of guidance for requirements capture before the design of new mobile computing systems.

One of the applications for the developed framework was the selection of mobile computing strategy for managing on-site construction information. The aim of the procedure for the selection of mobile computing strategy was to select the appropriate mobile computing strategy and related technologies to suit the specific characteristics of a construction project. The overall selection procedure had three major steps: the definition of on-site information management objectives, the identification of mobile computing strategy, and the selection of appropriate mobile computing technologies. This selection procedure should be conducted at the construction planning stage before the start of site works. The evaluation and validity of the selection procedure was demonstrated through an illustrative construction scenario. The desired objectives of integration at different levels can be achieved through the selection of different mobile computing strategies with regard to the user's requirements.

8.3 REALISATION OF AIM AND OBJECTIVES

The aim of this research project was to explore how mobile computing can be implemented to manage information on construction sites. The research concentrated on the identification of all major factors and their interrelationships which have impacts on the design, implementation, and application of mobile computing in on-site information management. The specific objectives of the research project were:

1 to investigate the concept of construction information management;
2 to investigate the state of the art mobile computing technologies and their practices in the construction industry;
3 to develop a framework to explore the use of mobile computing in construction site information management; and
4 to demonstrate the validity of the framework through an illustrative example.

In order to achieve the defined objectives of the research, various research methods and strategies were adopted in different research stages, see Section 4.6. Figure 8.1 shows a summary of how this research has satisfied these objectives with the description of the research methods, and the findings. From these results, the aims of the research project have been achieved through the literature review, findings of the survey, and the framework that identifies the key factors and their interrelationships, which provided guidance in the effective deployment and selection of mobile computing strategy for on-site information management.

Objective	Research Question	Research Method	Finding
1. To investigate the concept of construction information management.	What is the meant by construction information management?	Literature Review	The efficiency of information management is crucial to the construction industry. Research issues in the area of construction information management contributed lots of useful experiences. Current construction information management has several existing problems. Especially, the separation between site offices and construction work site and the separation between design and construction have restrained the adoption of 'concurrent engineering' strategy in the construction industry (Chapter 2.3).
	How do construction personnel manage information on construction sites?	Case Study	The varieties of roles on construction sites are normally affected by project stages, types and sizes. The key information on sites is drawings. IT support has been extended to construction site office, but construction work sites do not have sophisticated IT support and mobile computing is still a new concept to construction personnel (Chapter 5.2).
	What is the existing mechanism of information retrieval and transfer on construction sites?	Survey	Information needs of construction personnel are linked to their responsibilities. The major formats of drawings are graphics and image. Other on-site information is mostly presented by text. The project manager is the major source and destination of transferring on-site information. Major transfer mediums are meeting, email and post. Mobile computing is hardly used on work sites (Chapter 5.3).
2. To investigate the state of the art mobile computing technologies and their practices in the construction industry.	What are the current developments and practices of mobile computing in the construction industry?	Literature Review	The current available technologies to support on-site information management include mobile computers, wireless networks and mobile applications. Research in the area focuses on mobile computing technologies, mobile computing systems, evaluations and practices in construction, the investigation of its potential, challenges and benefits (Chapter 3).
3. To develop a framework to explore the use of mobile computing in construction site information management.	How can mobile computing be used on construction sites by construction personnel to manage on-site information?	Modelling	The framework identifies the key factors of mobile computing, construction personnel, construction information, and construction site, and explores the interrelationships and interactions between these factors (Chapter 6).
4. To demonstrate the validity of the framework through an illustrative example.	How can the developed framework be used in real construction situations?	Case study	One of the applications of the developed framework is the selection of mobile computing strategy for managing on-site construction information. The evaluation and validity of the selection procedure has been demonstrated through an illustrative construction scenario. The desired objectives of integration at different levels can be achieved through the selection of different mobile computing strategies regarding user's requirements (Chapter 7).

Figure 8. 1 Summary of objectives, research questions, research methods, and findings

8.4 BENEFITS OF THE DEVELOPED FRAMEWORK

In facilitating the implementation of mobile computing in construction, the developed framework of using mobile computing for construction site information management is of benefit to the industry in the following aspects:

- it identifies the three key factors of the mobile computing concept and their sub-factors.
- it identifies the three key factors and their sub-factors for the management of construction site information that determine the implementation of mobile computing.
- it represents the interrelationships between the user and mobile computing, the construction information and mobile computing, and the construction site and mobile computing.
- it provides the ways that mobile computing technologies can be used in the construction industry.
- it provides guidance in the effective deployment and selection of mobile computing for on-site information management.
- it helps users to understand and overcome the limitations and restrictions of using mobile computing technologies in the construction industry.
- it provides the possible uses of the framework, which includes the selection of a mobile computing strategy, the creation of a knowledge base for the development of a rule-based expert system, and the guidance of requirements captured for the design of new mobile computing systems.

- it can be used to evaluate the existing use of mobile computing on construction sites to find the technological restrictions and improve its consistent and reliable performance.

The benefits for the selection procedure derive from its use for the selection of mobile computing strategy and related technologies with respect to the characteristics of a specific project. In particular,

- It helps users to identify the desired objectives of on-site information management.
- It provides the various mobile computing strategies that users can select with respect to their desired objectives.
- It provides guidance for users to select appropriate mobile computing technologies to suit the characteristics of their projects.
- It ensures that the features of mobile computing technologies are considered to fit with current organisational systems.
- It ensures that the potentials of mobile computing can be explored for on-site information management for a specific project.
- It facilitates the decision making process for the selection of appropriate mobile computing strategies and related technologies.

8.5 CONTRIBUTION TO KNOWLEDGE

The originality of the research and its contribution to knowledge can be demonstrated in the research areas of on-site information management and mobile computing in construction.

8.5.1 CONTRIBUTION TO ON-SITE INFORMATION MANAGEMENT

In the research area of on-site information management, previous research usually focused on the identification of on-site construction information (de la Garza and Howitt, 1998; Scott and Assadi, 1999), construction information flow (Fisher and Yin, 1992), information needs of construction individuals (Tenah, 1986), and the problems and limitations existing in construction site information management (Bowden et al., 2004; Miah et al., 1998; Singhvi and Terk, 2003). The detailed review of construction information management can be found in Chapter 2.3. However, few researchers have discussed the actual mechanisms of on-site information communication in terms of the nature of on-site information, the source and destination of on-site information transfer, information transfer mediums, and information retrieval and transfer on work sites. Since mobile computing is recognised to have great potential in on-site information management, it was necessary to clarify the existing mechanisms of on-site information communications.

This research project investigated the existing mechanisms of on-site information communications in great depth. Through the web-based survey, the findings contributed to the research area of on-site information management from the following aspects: construction information that construction personnel retrieve to or transfer from sites, the nature of on-site information, the sources and destinations of on-site information communication, the transfer mediums of on-site information, and the approaches of information retrieval and collection on work sites. Additionally, this survey also identified roles on construction sites, investigated current on-site IT support, and explored construction personnel's perceptions to mobile computing in managing on-site information.

Because mobile computing mainly targets on-site information management, the understanding of current on-site information management mechanisms can provide the assistance for building the framework that identified the key factors and their interrelationships which provide the guidance in the deployment of mobile computing for on-site information management. The investigation of existing mechanisms also provided the general picture of current information management on construction sites for project managers, who can therefore improve the efficiency and effectiveness of current on-site information management through the use of new information technologies.

8.5.2 CONTRIBUTION TO MOBILE COMPUTING IN CONSTRUCTION

As a potential technology, mobile computing in construction is becoming a major research theme in the domain of Information Technology in Construction (ITC). According to the literature review (Chapter 3.8), current research in the area of mobile computing in construction concentrated on the implementation of a single mobile computing technology in construction (Beyh and Kagioglou, 2002; Domdouzis et al., 2005; Kuladinithi et al., 2004; Liu et al., 2003; Marsh and Finch, 1998; Menzel et al., 2004; Reinhardt et al., 2000; Sunkpho and Garrett, 2000), the design of mobile computing systems for specific construction processes (Kimoto et al., 2005; Magdic et al., 2004; Meissner et al., 2003; Tung and Hwang, 2002; Ward et al., 2003; Zeeshan et al., 2004), the evaluation of mobile computing technology in a construction environment (Bowden et al., 2003; de la Garza and Howitt, 1998; Magdic et al., 2002; Saidi et al., 2002; Ward et al., 2003), and the identification of its potential (ARUP, 2003; Saidi et al., 2002), challenges (Anumba et al., 2003; Magdic et al., 2002) and benefits (Bowden et al., 2006; de la Garza and Howitt, 1998; Olofsson and Emborg, 2004; Rebolj et al., 2001).

However, most research in this area focused on detailed aspects or single facets of mobile computing and the implementation in a single construction process. As one technology overtakes other technical solutions, it should be more consistent and reliable. Therefore, it is reasonable to concentrate on general concepts and the internal relationships between the two areas of mobile computing and construction site information management. Because of the complex nature of the construction site environment, the variety of on-site information, and the features of mobile computing, the implementation of mobile computing has to consider the interrelated factors that can affect the performance of mobile computing technologies in order to fulfil users' requirements. However, those key factors and their interrelationships were not clearly identified in previous research, and then the development of the framework that identified key factors and their interrelationships was essential to provide guidance in the effective deployment and selection of mobile computing for on-site information management.

The developed framework as the key output of this research contributed to knowledge through the identification of key factors and their interrelationships in the implementation of mobile computing in on-site construction information management.

The framework identified three independent factors including 'user', 'construction information' and 'construction site', which were the elements that indicated the specific construction environment and determined the use of mobile computing in this particular context. The three components of the concept of mobile computing - 'mobile computer', 'wireless network' and 'mobile application' - were also identified as the dependent factors because the implementation of mobile computing should depend on the various construction circumstances decided by independent factors. In order to explore the interrelationships between independent and dependent factors, the key factors were further divided into sub-factors and the framework was therefore broken down to various sub-frameworks, each of which represented the detailed relationships between two key factors.

The potential applications of the developed framework included the selection of mobile computing strategy, the creation of the knowledge base for the development of a rule-based expert system, and the guidance for requirements captured before designing a new mobile computing system. The selection of mobile computing strategy included three major stages: the definition of on-site information management objectives, the identification of mobile computing strategy, and the selection of appropriate mobile computing technologies. In the third stage, mobile computing technologies would be selected based on the developed framework, and the restrictions and interrelationships that may facilitate or inhibit the implementation of mobile computing would be also identified. This framework can be applied to evaluate the existing uses of mobile computing on construction sites in order to find the technological restrictions and improve the consistent and reliable performance of current mobile computing technologies.

8.6 RESEARCH LIMITATIONS

The quality of research findings are dependent upon the choice of research methodology, the reliability of the data gathered, and the applicability of the statistical tools used. Constraints and limitations on the reliability of results include the validity of the research instrument, the validity of data gathered, the validity of the model developed, and finally the validity of the conclusion drawn (Walker, 1997).

According to this research, the recognised limitations and constraints include the following aspects:

- The research instrument of questionnaire allows people to decide whether or not to reply. Although reminder emails were sent out to the target population in the later stages in order to increase the return rate, not all the target population completed the questionnaire. Therefore the results may not be wholly representative of the target population. This limitation may be overcome by using another research instrument, interviews, that can obtain a balanced representation of opinions from relatively smaller samples.
- Because construction sites are high risk areas, site managers could not allow the author access to the actual work sites. On-site construction personnel were normally very busy conducting their construction activities according to the strict project schedule. Therefore, the case studies based on construction sites were constrained in the visited site areas which included site offices and the edge of work sites. A number of factors including respondents' available time, interview accommodation, the understanding of interview questions and their relevance to this research topic, have affected the interview process with respect to the quality, depth, and extent of

obtained views. Therefore, caution must be exercised in extrapolating these results and they should only be considered indicative.

- In order to develop the framework for using mobile computing in on-site information management, it is especially helpful and practical to conduct case studies that apply mobile computing technologies in real construction projects, and to test and evaluate mobile computing technologies in real construction sites. However, there were several reasons that constrained the practical test and technical evaluation. First, because mobile computing technologies were not widely adopted and practically applied by most construction organisations to manage on-site information, it was especially difficult to find appropriate construction projects during the period of the research. Second, because of the high risk area of construction sites and the strict schedule of construction activities for on-site personnel, it was extremely difficult to obtain permission to test mobile computing technologies on real construction sites or to persuade on-site construction personnel to conduct the mobile computing experiments. Finally, the research was limited by resources. This research project is a PhD thesis research, and the research strategy was developed, data gathered and analysis undertaken by only one person with a limited time resource of three years and no research funding. Mobile computers such as PDAs, Pocket PC, and Tablet PCs are normally expensive, several hundreds pounds, and the purchasing of mobile computing equipment was restricted by the financial budget.
- The developed framework for using mobile computing in on-site construction information management only concerned the limited factors that impact on the implementation of mobile computing. Other factors that may affect the application of mobile computing technologies may include the cost, existing organisational

information systems, and the specific construction project. All of the remained factors should be investigated and explored in future research.

8.7 RECOMMENDATIONS AND FURTHER WORK

Areas for future research include the following:

8.7.1 THE PROCEDURE FOR THE SELECTION OF MOBILE COMPUTING STRATEGY

The procedure for selecting mobile computing strategy can be improved and enhanced through a number of methods:

- A further investigation of construction projects that currently implement mobile computing can provide an understanding of users' decision-making processes for the selection of mobile computing technologies. A comparison of the real decision-making process with the developed procedure can revise the procedure to suit users' real decision-making processes, and finally make the improvement of real decision-making processes more effective and precise.
- A further investigation of the projects that currently apply mobile computing can identify more mobile computing strategies that can be used for the selection procedure to suit different user requirements.
- Use of the selection procedure on a wide range of projects is essential to further test its applicability to different project types.
- The developed procedure provides the guidance for the further design of mobile computing system on construction sites.

- Further research should be conducted from the user's perspective such as whether users need the selection procedure, who needs it, how users can use it, and how the selection procedure can provide useful guidance to users.

8.7.2 THE FRAMEWORK OF USING MOBILE COMPUTING IN ON-SITE INFORMATION MANAGEMENT

Areas for further research with respect to the developed framework include:

- The testing and evaluation of mobile computing technologies including mobile computers, wireless networks, and mobile applications, on real construction work sites. These can enhance the developed framework through improved awareness of existing factors and interrelationships and the identification of new factors and links.
- The testing of mobile computing systems for a specific construction process on sites. This test can demonstrate the potential and benefits of using mobile computing in construction and encourage the adoption of mobile computing in the construction industry.
- The identification of new factors. New factors such as cost, existing information systems and construction processes, can be analysed and identified through the case studies of the construction projects that currently apply mobile computing technologies.
- The development of other potential applications for the developed framework. The potential applications of this framework include the development of the knowledge base for rule-based expert systems to select mobile computing technologies and the guidance for requirements capture in the design of new mobile computing systems.

8.8 CLOSING COMMENTS

Effective communication on construction sites is a key component of the integrated design and construction. Current construction site information communication methods prevent effective information access at construction work sites and hinder improvements in the deficiency of communication between construction and design. The emergence of mobile computing has the potential to widen the boundary of IT support from site offices to actual work sites and improve information communication between fieldworkers and the design team. However, current research in the area of mobile computing in construction focuses on detailed aspects or single facets of mobile computing and the implementation in single construction process. The research documented in this thesis has explored a framework of how mobile computing can be used on construction sites to manage on-site information, and identified the procedure for the selection of mobile computing strategy based on the developed framework. This framework can be further extended to develop the knowledge base for a rule-based expert system and the guidance for requirements captured in the design of new mobile computing systems.

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APPENDIX 1:

PUBLICATIONS ARISING FROM THE RESEARCH

PAPER 1:

Chen, Y., and Kamara, J. M. (2005). "Mobile computing and information management in construction." 3rd International Conference on Innovation in Architecture, Engineering and Construction, S. Sariyildiz and B. Tuncer, eds., Rotterdam, The Netherlands, pp. 797-806.

PAPER 2:

Chen, Y., and Kamara, J. M. (2005). "The use of mobile computing in construction information management." Proceedings of the 21st Annual Conference of the Association of Researchers in Construction Management, F. Khosrowshahi, ed., SOAS, London, ARCOM, pp. 581-590.

PAPER 3:

Chen, Y., and Kamara, J. M. (2006). "Managing construction site information using mobile computing." The Joint International Conference on Construction Culture, Innovation and Management (CCIM), M. Dulaimi, ed., Dubai.

PAPER 4:

Chen, Y., and Li, X. Y. (2006). "Mobile computing and construction site information management." Proceedings of the 13th Chinese National Conference on IT in Civil Engineering, D. HAN, Y. HUANG, and K. ZHANG, eds., SCUT Press, GuandDong, China. (in Chinese)

PAPER 5:

Chen, Y., and Kamara, J. M. (in press). "Using mobile computing for construction site information management." *Engineering Construction and Architectural Management.*

APPENDIX 2:

MOBILE COMPUTING PRODUCTS

Picture A2.1: Cingular 2125 Smart-Phone

Software and Features	
Operating System	Windows Mobile 5.0 for Smartphone
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes ClearVue viewer for Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Direct Push E-Mail	Upgrade Available
Notes	No
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	Cyberon VR
Hardware	
Processor	TI OMAP 850 200 MHz
Dimensions	4.57"x1.81"x0.69
Weight	3.74 ounces
Display resolution	320x240
QWERTY keyboard	No
Touch screen with stylus	No
Camera	1.3 mega pixel camera with camcorder; Video capture supports M-JPEG AVI, MPEG-4,
Built-in memory	64 MB Flash ROM
Expandable memory	miniSD
Manufacturer stated battery life	Talk time: up to 4 hours, Standby time: up to 6 days
Speakerphone	Yes
Connectivity	
Bluetooth	Version 1.2, class 2
WiFi	No
Infrared	Yes
Wireless connectivity	GSM
Data connectivity	GPRS/EDGE

Table A2.1: Cingular 2125 Smart-Phone Specifications

Picture A2.2: T-Mobile SDA Smart-Phone

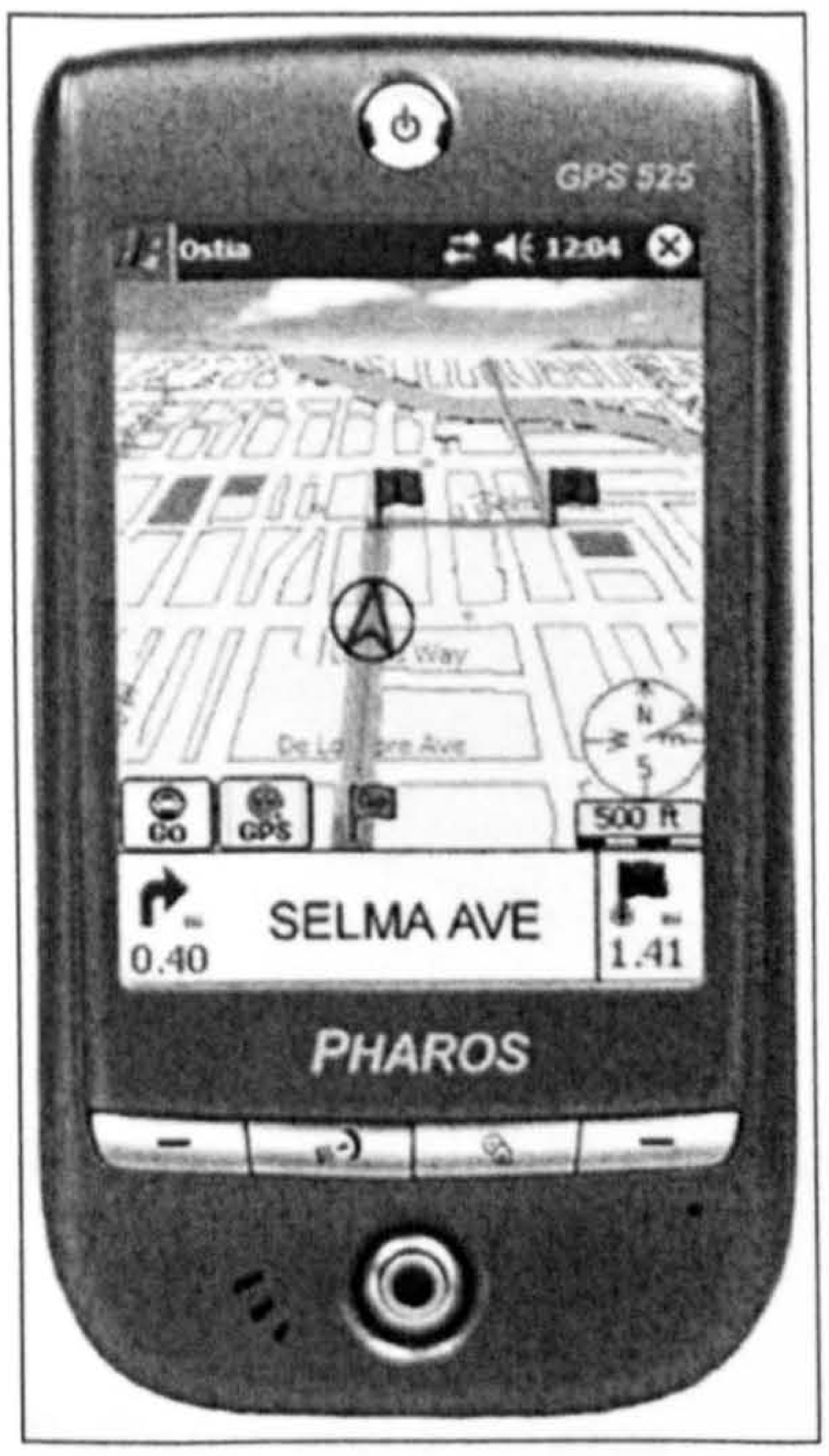
Software and Features	
Operating System	Windows Mobile 5.0 for Smartphone
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes ClearVue viewer for Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Direct Push E-Mail	No
Notes	No
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	No
Hardware	
Processor	TI OMAP 850 200 MHz
Dimensions	4.57"x1.81"x0.69
Weight	3.74 ounces
Display resolution	320x240
QWERTY keyboard	No
Touch screen with stylus	No
Camera	1.3 mega pixel camera with Video capture
Built-in memory	64 MB RAM, 64 MB ROM
Expandable memory	miniSD
Manufacturer stated battery life	Talk time: up to 4.5 hours, Standby time: up to 8 days
Speakerphone	Yes
Connectivity	
Bluetooth	Yes
WiFi	Yes
Infrared	No
Wireless connectivity	GSM
Data connectivity	GPRS/EDGE

Table A2.2: T-Mobile SDA Smart-Phone Specifications

Picture A2.3: Orange SPV C600 Smart-Phone

Software and Features	
Operating System	Windows Mobile 5.0 for Smartphone
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	No
Microsoft Internet Explorer Mobile	Yes
Direct Push E-Mail	No
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	No
Hardware	
Processor	Unknown
Dimensions	1.7.7x45.9x18.8 mm
Weight	107g
Display resolution	320x240
QWERTY keyboard	No
Touch screen with stylus	No
Camera	1.3 mega pixel camera with Video capture
Built-in memory	64 MB
Expandable memory	miniSD
Manufacturer stated battery life	Talk time: up to 4 hours, Standby time: up to 6 days
Speakerphone	Yes
Connectivity	
Bluetooth	Yes
WiFi	No
Infrared	No
Wireless connectivity	GSM
Data connectivity	GPRS/EDGE

Table A2.3: Orange SPV C600 Smart-Phone Specification



Picture A2.4: Pharos Traveler GPS 525 Pocket PC

Software and Features	
Operating System	Windows Mobile 5.0 for Pocket PC
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	No
Hardware	
Processor	SC32442X 300MHx
Dimensions	2.4"x4.3"x0.7"
Weight	150 grams
Display resolution	240x240
QWERTY keyboard	No
Touch screen with stylus	Yes
Camera	No
Built-in memory	64 MB RAM, 128MB ROM
Manufacturer stated battery life	GPS model: 5 hours, Standby time: 200 hours
Expansion Slot	SDIO expansion slot
Connectivity	
Bluetooth	Yes
WiFi	Yes
Infrared	Yes

Table A2.4: Pharos Traveler GPS 525 Pocket PC Specification

Picture A2.5: CV30 Fixed Mount Computer

Software and Features	
Operating System	Windows Mobile 5.0 for Pocket PC
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Hardware	
Processor	PXA270 based on Intel XScale technology 520 MHz
Dimensions	7.45"x2.15"x6.95"
Weight	3.25 lbs
Display resolution	640x480
QWERTY keyboard	No
Touch screen with stylus	Yes
Camera	No
Built-in memory	128 MB RAM, 128MB ROM
Manufacturer stated battery life	Unknown
Expansion Slot	128MB Disk on chip Flash Memory for onboard non-volatile storage of applications and data
Connectivity	
Bluetooth	Yes
WiFi	Yes
Infrared	No

Table A2.5: CV30 Fixed Mount Computer Specification

Picture A2.6: TDS Ranger Pocket PC

Software and Features	
Operating System	Windows Mobile 5.0 for Pocket PC
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Hardware	
Processor	Intel PXA 270 Xscale 312 MHz (Ranger 300X) or 520 MHz (Ranger 500X)
Dimensions	10.5"x5.2"x1.9"
Weight	2.1 lb
Display resolution	240x320
QWERTY keyboard	Yes
Touch screen with stylus	Yes
Camera	No
Built-in memory	64 MB or 128 MB RAM, 256MB or 512 MB ROM
Manufacturer stated battery life	30 hours
Expansion Slot	(SD) slot and SDIO-enabled
Connectivity	
Bluetooth	Yes
WiFi	No
Infrared	No

Table A2.6: TDS Ranger Pocket PC Specification

Picture A2.7: T-Mobile MDA Pocket PC Phone

Software and Features	
Operating System	Windows Mobile 5.0 for Pocket PC Phone
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Direct Push E-Mail	Yes (with the maintenance release)
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	No
Hardware	
Processor	TI OMAP 850 200MHz
Dimensions	4.29"x2.28"x0.93"
Weight	5.64 ounces
Display resolution	240x320
QWERTY keyboard	Yes
Touch screen with stylus	Yes
Camera	1.3 mega pixel
Built-in memory	64 MB RAM, 128 MB ROM
Manufacturer stated battery life	Talk time: up to 5 hours, Standby time: up to 10 days
Expandable memory	miniSD
Speakerphone	Yes
Connectivity	
Bluetooth	Yes
WiFi	No
Infrared	No
Wireless connectivity	GSM
Data connectivity	EDGE/GPRS

Table A2.7: T-Mobile MDA Pocket PC Phone Specification

Picture A2.8: Palm Treo 750 Pocket PC Phone

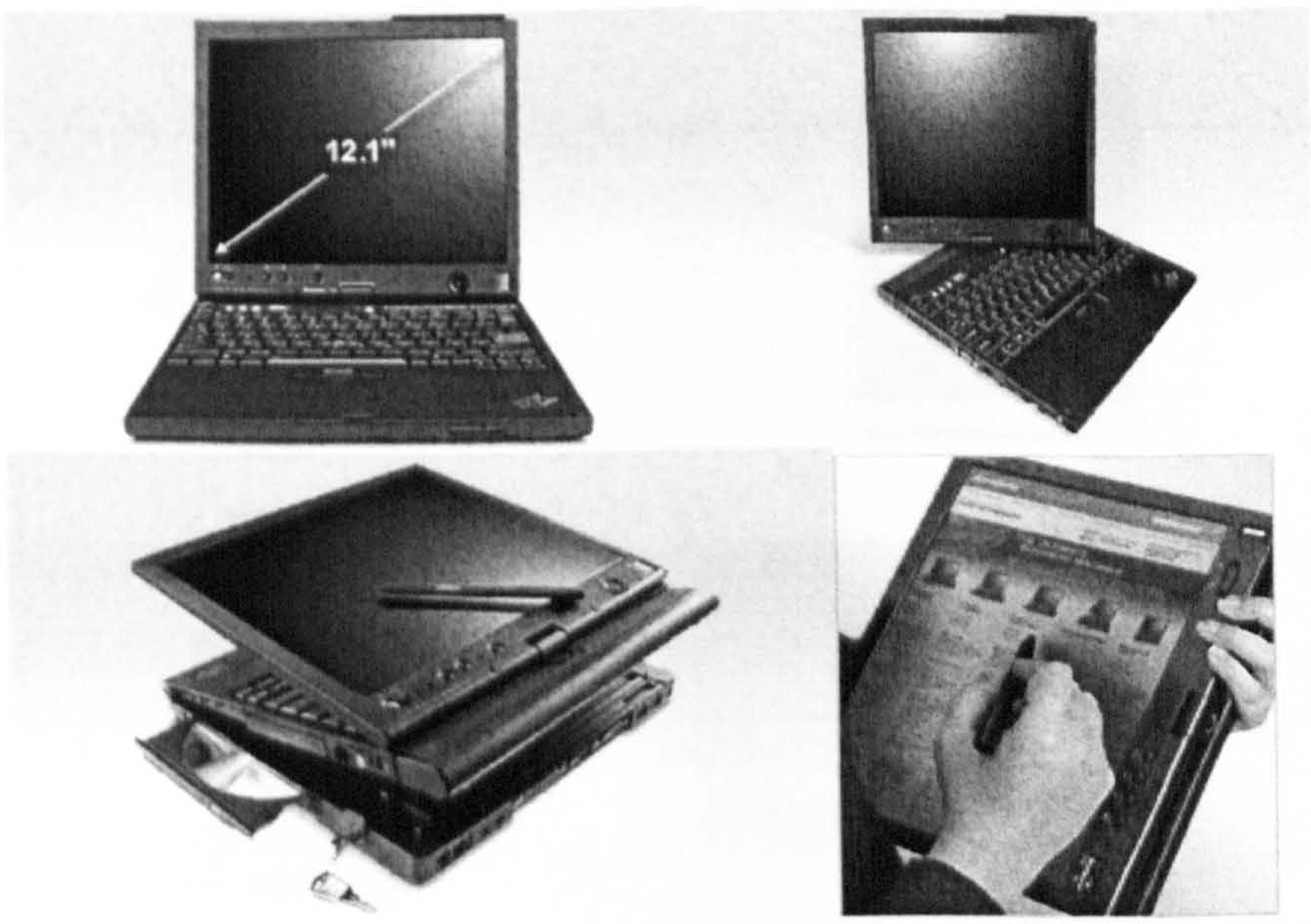
Software and Features	
Operating System	Windows Mobile 5.0 for Pocket PC Phone
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Direct Push E-Mail	Yes
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	Yes
Hardware	
Processor	Samsung 300MHz
Dimensions	4.4”x2.3”x0.8”
Weight	5.4 ounces
Display resolution	240x240
QWERTY keyboard	Yes
Touch screen with stylus	Yes
Camera	1.3 mega pixel with video capture support
Built-in memory	64 MB RAM, 128 MB ROM
Manufacturer stated battery life	Talk time: up to 4 hours, Standby time: up to 250 hours
Expandable memory	miniSD
Speakerphone	Yes
Connectivity	
Bluetooth	Yes
WiFi	No
Infrared	Yes
Wireless connectivity	GSM – Quad-band and UMTS – Tri-band
Data connectivity	Tri-band UMTS and EDGE/GPRS

Table A2.8: Palm Treo 750 Pocket PC Phone Specification

Picture A2.9: MC9097-G Pocket PC Phone

Software and Features	
Operating System	Windows Mobile 5.0 for Pocket PC Phone
Microsoft Outlook Mobile	Includes contacts, calendar, tasks, e-mail, text messaging
Microsoft Office Mobile	Includes Microsoft Word, Excel, and PowerPoint
Microsoft Internet Explorer Mobile	Yes
Direct Push E-Mail	No
Notes	Yes
Pocket MSN	Yes
Windows Media Player	Includes support for Windows Media Audio (WMA), Windows Media Video (WMV), and MP3
Voice Recognition	Nextel Nationwide Walkie Talkie
Hardware	
Processor	Intel XScale Bulverde PXA270 624MHz
Dimensions	3.6"x2.2"
Weight	20-23 ounces
Display resolution	3.8 in. QVGA color
QWERTY keyboard	No
Touch screen with stylus	No
Camera	No
Built-in memory	128MB Flash
Manufacturer stated battery life	At least 9 hours
Expandable memory	SD/MMC
Speakerphone	Yes
Connectivity	
Bluetooth	Yes
WiFi	No
Infrared	No
Wireless connectivity	iDEN (WiDEN)
Data connectivity	iDEN (WiDEN)

Table A2.9: MC9097-G Pocket PC Phone Specification



Picture A2.10: ThinkPad X60 Tablet PC

Software and Features	
Operating System	Genuine Windows Vista Business
Microsoft Outlook	Yes
Microsoft Office	Yes
Microsoft Internet Explorer	Yes
Preloaded Software	Adobe Reader, Diskeeper Lite, Multimedia Center, PC-Doctor, Symantec Client Security, ThinkPad Utilities, Zinio Reader,
Hardware	
Processor	Core Duo L2500 LV (1.83GHz, 2MB L2, 667MHz FSB)
Dimensions	274x267x27.4-33.1mm
Weight	1.92kg
Display Size	12.1" Multi-View/Multi-Touch XGA TFT
Display resolution	1024x768, 150 nits
QWERTY keyboard	Yes
Touch screen with stylus	Yes
Camera	No
Built-in memory	Up to 4GB PC2-4200/533 MHz
Hard disk drive	Up to 100GB 7200 rpm
Optical drive	CD/DVD-ROM
Manufacturer stated battery life	Up to 7.5 hours
Ports	3 USB 2.0, Infrared, expansion bus, external display, AC adapter, RJ-11, RJ-45, audio: headphone/line-out, external microphone
Keyboard	Ergonomic keyboard with palm rest, TrackPoint pointing device, Internet Scroll Bar,
Connectivity	
Bluetooth	Yes
Infrared	Yes
Ethernet	Yes
Moderm	Yes
WLAN	Yes
WWAN	Yes
GPS	No
Rugged and weatherized feature	No

Table A2.10: ThinkPad X60 Tablet PC Specification

Picture A2.11: Stylistic® ST5111/ST5112 Tablet PC

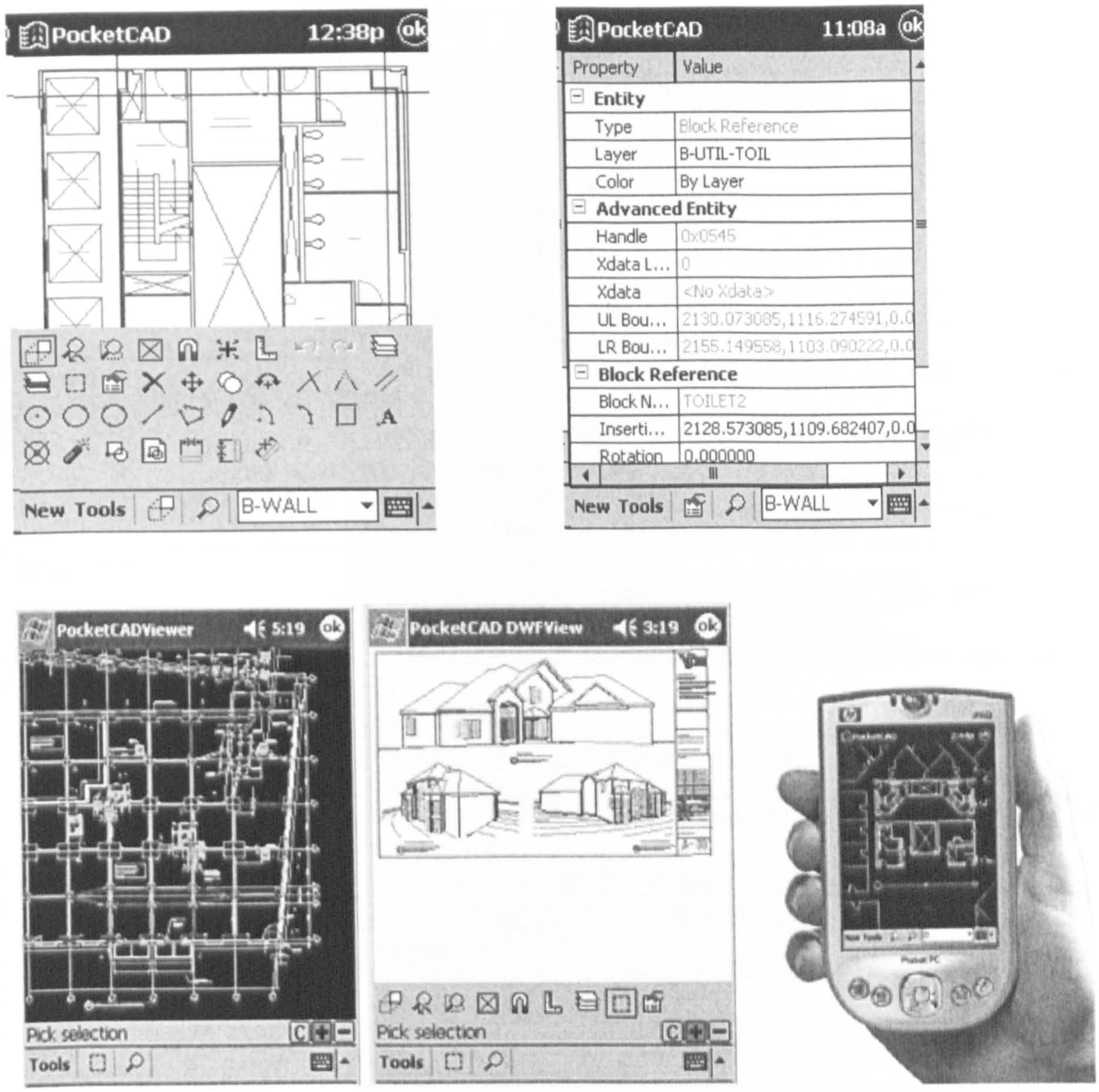
Software and Features	
Operating System	Genuine Windows Vista Capable
Microsoft Outlook	Yes
Microsoft Office	Yes
Microsoft Internet Explorer	Yes
Preloaded Software	Adobe Reader, Microsoft Office OneNote 2003, Microsoft Experience Pack for Tablet PC, Microsoft Windows Journal,
Hardware	
Processor	Intel Core Duo Processor U2500 (1.20GHz, 2MB L2, 533MHz FSB)
Dimensions	12.77"x8.66"x82-.88"
Weight	3.5 lbs
Display Size	12.1" XGA TFT
Display resolution	1024x768,
QWERTY keyboard	No
Touch screen with stylus	Yes
Camera	No
Built-in memory	Up to 4GB PC2-4200/533 MHz
Hard disk drive	Up to 40GB 5400 rpm
Optical drive	CD/DVD-ROM
Manufacturer stated battery life	Up to 9 hours
Ports	2 USB 2.0, Infrared, expansion bus, AC adapter, RJ-11, RJ-45, audio: headphone/line-out, wireless IR keyboard/mouse receivers,
Pointing Device	Digitizer Control Panel Touch-screen and Passive Touch-screen Standard
Connectivity	
Bluetooth	Yes
Infrared	Yes
Ethernet	Yes
Moderm	Yes
WLAN	Yes
WWAN	Yes
GPS	No
Rugged and weatherized feature	No

Table A2.11: Stylistic® ST5111/ST5112 Tablet PC Specification

Picture A2.12: Tronix Duo-Touch Tablet PC

Software and Features	
Operating System	Microsoft Windows XP Tablet PC Edition
Microsoft Outlook	Yes
Microsoft Office	Yes
Microsoft Internet Explorer	Yes
Preloaded Software	Unknown
Hardware	
Processor	Intel Pentium M Processor 733 (1.1GHz, 2MB L2)
Dimensions	270x184x42mm
Weight	4.1 lbs
Display Size	8.4" SVGA TFT
Display resolution	1024x768,
QWERTY keyboard	No
Touch screen with stylus	Yes
Camera	No
Built-in memory	Up to 1280GB PC2-4200/533 MHz
Hard disk drive	Up to 80GB 5400 rpm
Optical drive	No
Manufacturer stated battery life	Up to 8 hours
Ports	2 USB 2.0, PC Card slot, expansion bus, AC adapter, RJ-11, RJ-45, 26-pin docking connector, external speaker and microphone,
Pointing Device	Digitizer Control Panel Touch-screen and Passive Touch-screen Standard
Connectivity	
Bluetooth	Yes
Infrared	Yes
Ethernet	Yes
Moderm	Yes
WLAN	Yes
WWAN	Yes
GPS	Yes
Rugged and weatherized feature	Tested for shock, drop and vibration, shock-mounted hard drive, Die-cast magnesium case, hazardous location certified, resistant to water and dust

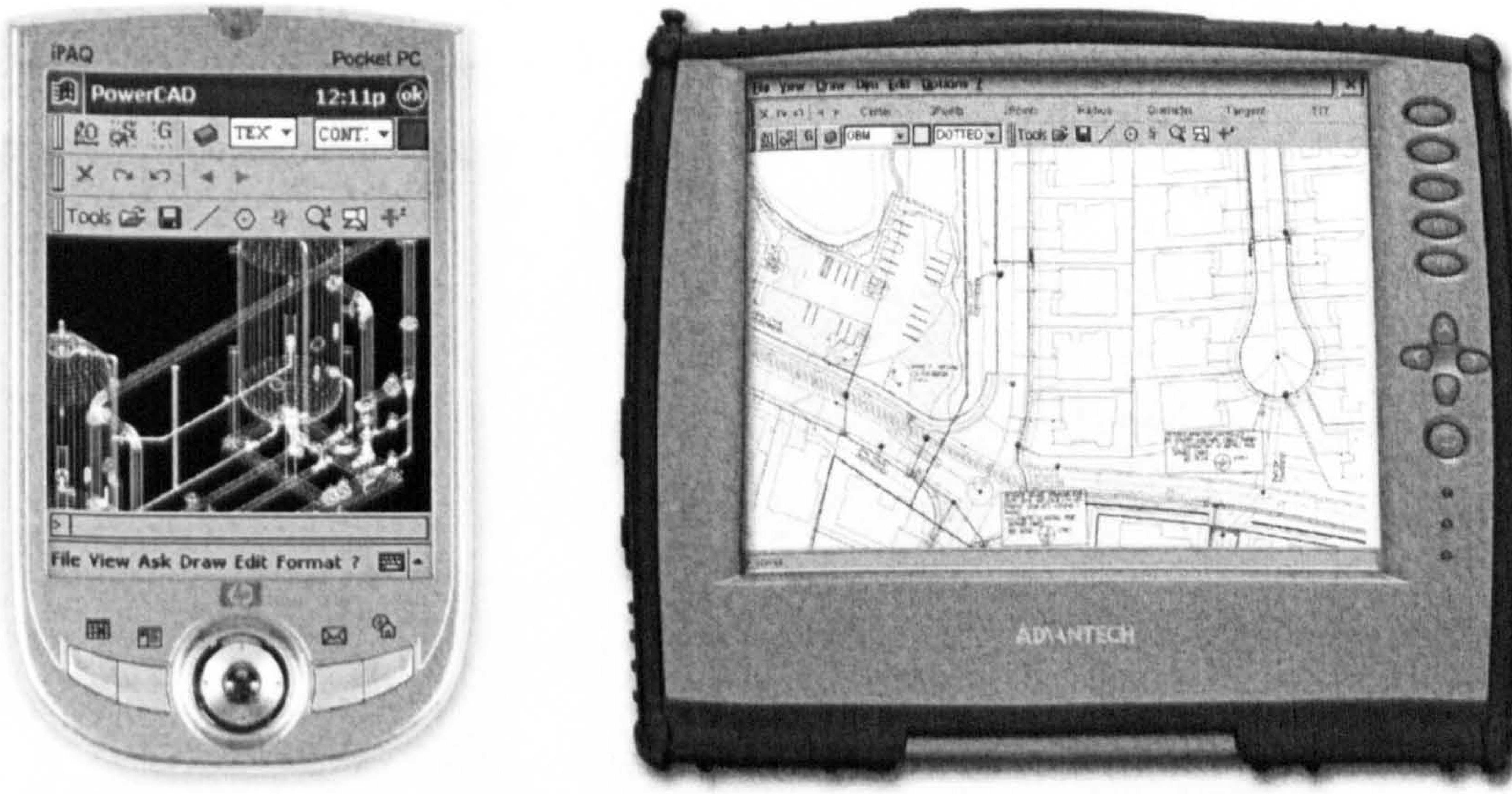
Table A2.12: Tronix Duo-Touch Tablet PC Specification



Picture A2.13: Mobile CAD Applications

Compatibility	Reads and writes AutoCAD DWG and DXF drawings and MicroStation DGN files
	Compatible with most desktop CAD software
	Runs on any Windows powered Pocket PCs
General	Programmable – build or use custom add-ins
	Pop-up tool bar and Hint window
	Black or white background colour
	File Open/Save menu
	Coordinate display
	Template drawing
	Data stored 3D double precision
Viewing	View AutoCAD DWG and DXF drawings and MicroStation DGN files
	Zoom in and out, zoom window, zoom previous, zoom extents, pan
	One hand pan and zoom
	Query entities for properties
	Measure distance and angle between entities
Drawing	Make changes in field
	Create circles, lines, rectangles, arcs and 2D/3D poly-lines
	Create points and select point size and elevation
	Supports Architectural, Survey, Engineering, Decimal and Fractional Units
	Freehand sketch
	Set colour with 256 colour picker window
	Create and edit layers
	Set points to define relative distances and directions, absolute X/Y, relative X/Y
	Create, edit and explored blocks and blocks with attributes
	Pick Points allow for accurate drawing
	Annotate and label
Edit	Edit drawings using extensive features including multi-cutting edge trim and extend
	Copy, offset, rotate, move and delete
	Multiple Undo and Redo
	Select entity and edit properties including colour, position, size, layer
Measure	Select points on screen and get distance, angle and X and Y offset
	Dimension horizontal, vertical and align
Edit Track	Automatically tracks and records file updates to simplify updates and protect master files
	Preserves Paper-space/Model-space layouts, 3D solids, text and dim settings, poly-line widths and line type styles
File Transfer	Use CADExchange to transfer files or drag and drop from desktop using Microsoft ActiveSync
	Upload PocketCAD file as a new DWG, DXF, or DGN file or merge edits into existing DWG, DXF, or DGN file on desktop

Table A2.13: PocketCAD Features and Specifications



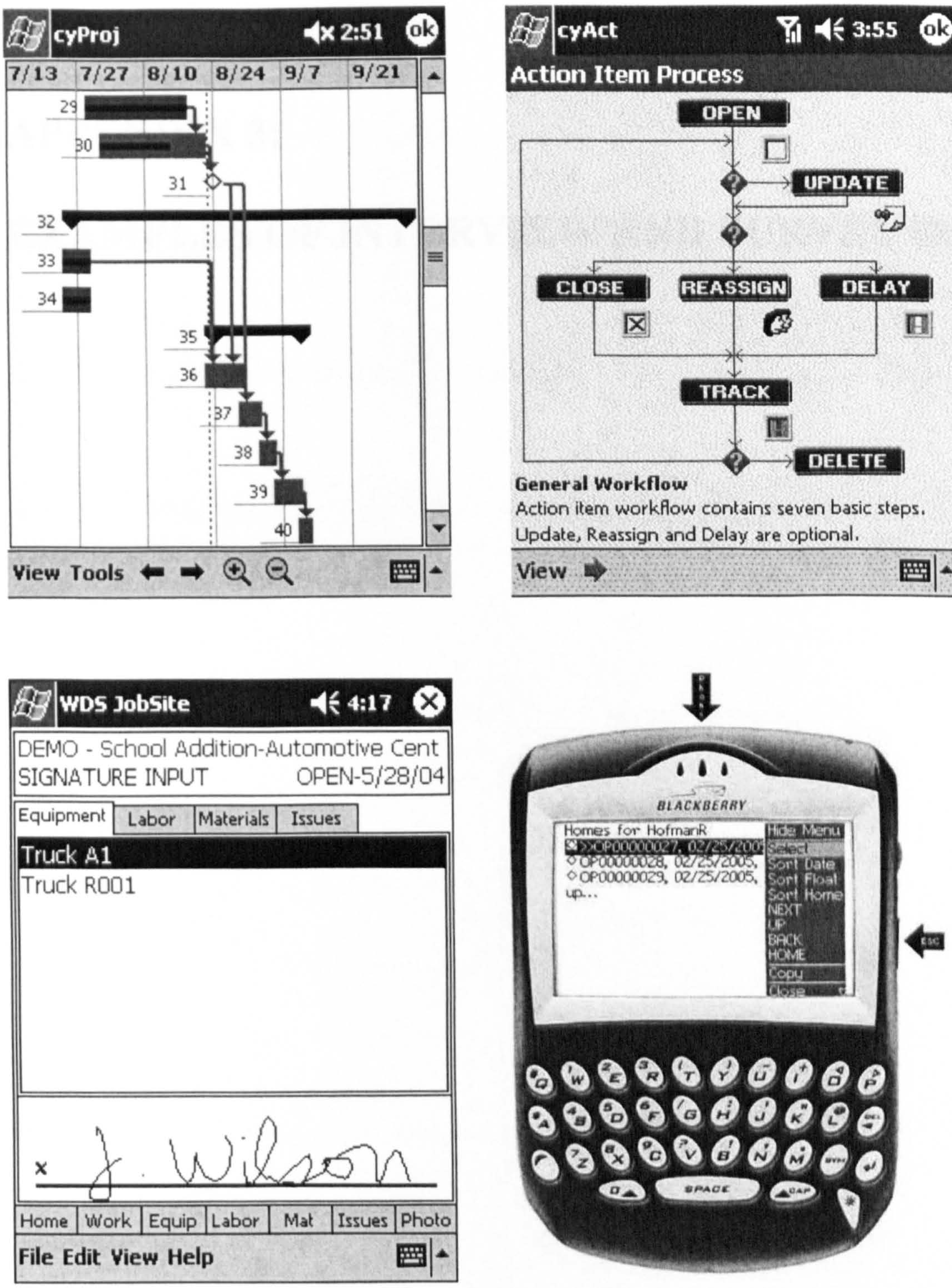
Picture A2.14: PowerCAD CE Applications

Compatibility	Optimized for Pocket PCs running Windows CE or Windows Mobile
	Read FelixCAD Flx, AutoCAD DWG and DXF files
	Write FLX, DWG and DXF files for syncing with FelixCAD FelixCADLT, AutoCAD and other desktop systems
	Run Lisp and C/C++ program extensions
General	Simplified menu with pop-up commandline supporting 1-3 character shortcuts
	Run macros and scripts
	Load custom menus and toolbars
	Create custom menus, dialogs and toolbars
	Create custom extensions and applications using programming interface
Viewing	View drawings in 2D/3D with real-time zooming and panning
Drawing	AutoCAD compatible layers, text, line types, hatch patterns, entities and commands
	Free-hand sketching and mark-up of drawings
	Create new drawings in the field
	Create associative dimensioning and hatching
	3D poly-line creation and editing
	Create solid filled 2D polygons
	Create advanced 3D objects including boxes, wedges, spheres and toruses
Edit	Edit drawings using over 200 standard and advanced 2D drawing tools
	AutoCAD compatible layer manager
	Externally referenced drawing manager
File Transfer	Microsoft ActiveSync support

Table A2.14: PowerCAD CE Features and Specifications

Picture A2.15: ZipCAD Applications

Picture A2.16: Mobile data capture applications



Picture A2.17: Project Management Applications

APPENDIX 3:

EXAMPLES OF INTERVIEW AND SURVEY DATA

Interviews

Project Name: Theatre refurbishment project
Construction Site: Single-site, medium size
Project Value: 3 million pound
Project Construction Time: 12 months

1. **What is your role in the project team?**
   Demolition Supervisor

2. **What information do you need on construction sites?**
   Engineering drawings, progress information, specifications, contracts, quantities and productivity information, field labour information

3. **How often do you visit construction site?**
   5 days a week, at least 6 hours at a time

4. **What are your responsibilities?**
   Make sure all jobs done, make sure that jobs are done within required time, budget, and quality standards, organise supervise field labours, supervise health and safety issues

5. **What do you think about the use of mobile computers on construction sites?**
   Not sure.

Interviews

Project Name: Theatre refurbishment project
Construction Site: Single-site, medium size
Project Value: 3 million pound
Project Construction Time: 12 months

1. **What is your role in the project team?**
   Ground worker

2. **What information do you need on construction sites?**
   Supervisor's instructions, quality information, safety information

3. **How often do you visit construction site?**
   5 days a week, 7 hours a day.

4. **What are your responsibilities?**
   Ground job, dig holes,

5. **What do you think about the use of mobile computers on construction sites?**
   Not sure.

Interviews

Project Name: Theatre refurbishment project
Construction Site: Single-site, medium size
Project Value: 3 million pound
Project Construction Time: 12 months

1. **What is your role in the project team?**
   Site engineer

2. **What information do you need on construction sites?**
   Drawings, specifications, material information, equipment information, design information, quality information, engineering methods, safety information,

3. **How often do you visit construction site?**
   5 days a week, at least 4 hours at a time

4. **What are your responsibilities?**
   Control construction processes on sites, make site records, prepare site reports, read and interpret drawings and specifications, inspect work

5. **What do you think about the use of mobile computers on construction sites?**
   Don't know.
   Mobile computers may be used in big construction site.

Interviews

Project Name: Sports centre extension project and medical school reform project
Construction Site: Multi-sites, medium size
Project Value: 13.5 million pound
Project Construction Time: 15 months

1. **What is your role in the project team?**
   Project manager

2. **What information do you need on construction sites?**
   All project-related information

3. **How often do you visit construction site?**
   Three times one week, 2 hours at a time

4. **What are your responsibilities?**
   Make sure the project completed at required quality, time, and budget, organise and coordinate construction personnel involved in the project, supervise and inspect all construction jobs

5. **What do you think about the use of mobile computers on construction sites?**
   Mobile computers can increase the efficiency of collecting data on construction sites. Mobile computers need to be fully tested before the use on sites.

Interviews

Project Name: Sports centre extension project and medical school reform project
Construction Site: Multi-sites, medium size
Project Value: 13.5 million pound
Project Construction Time: 15 months

1. **What is your role in the project team?**
   Quantity survey

2. **What information do you need on construction sites?**
   Drawings, quantity and rates, sub-contractor information, man hours, work sheets, time sheets, schedule

3. **How often do you visit construction site?**
   Once a week

4. **What are your responsibilities?**
   Financial management, prepare cost reports, analyse and control cost

5. **What do you think about the use of mobile computers on construction sites?**
   Don't know.

Interviews

Project Name: Sports centre extension project and medical school reform project
Construction Site: Multi-sites, medium size
Project Value: 13.5 million pound
Project Construction Time: 15 months

1. **What is your role in the project team?**
   Civil engineer

2. **What information do you need on construction sites?**
   Drawings, specifications, design details, contracts, equipment information, progress information, safety information, quality standards

3. **How often do you visit construction site?**
   5 days a week, 5 hours at a time

4. **What are your responsibilities?**
   Manage and control construction processes, ensure safety and quality standards satisfied, solve engineering problems

5. **What do you think about the use of mobile computers on construction sites?**
   The size of PDA screen is too small for construction drawings. Construction personnel prefer to use paper-based drawings that can be hung on the wall, so it is easy to discuss any construction details.

Interviews

Project Name: Water supply project
Construction Site: Single-sites, medium size
Project Value: 5 million pound
Project Construction Time: 6 months

1. **What is your role in the project team?**
   Consultant

2. **What information do you need on construction sites?**
   Drawings, specifications, design details, contracts, progress information, quality standards

3. **How often do you visit construction site?**
   5 days a week, around 4 hours at a time

4. **What are your responsibilities?**
   Make sure construction jobs are completed based on designs.

5. **What do you think about the use of mobile computers on construction sites?**
   Don't know.

Interviews

1. What is your role and responsibilities in this project?
Business procedures manager, temporary works as coordinator and engineer on the project

2. What construction tasks are you currently involved on construction site?
Involved in all the construction processes, consulted on engineering aspects of the construction tasks

3. What construction information do you need at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	
Equipment Information		Progress Information	
Design Clarification		Construction Methods	X
Sub-contractor Information	X	Labour Information	
Quality Information	X	Safety Information	X
Site Visit Record			

Where do you receive these kinds of information from?
People (sub-contractor's supervisors)
Computer System
Document in site office

4. What construction information do you collect at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings		Material Information	
Equipment Information		Progress Information	
Design Clarification		Construction Methods	X
Sub-contractor Information	X	Labour Information	
Quality Information	X	Safety Information	
Site Visit Record			

Where do you transfer these kinds of information to?
Computer System
Document in site office

5. How do you process construction information at field (outside site office) (Please tick appropriate box)?

View	X	Edit		Draw		Mark Up	X	Write	
Update	X	Check	X	Clarify	X	Collect Data			

Interviews

1. What is your role and responsibilities in this project?
Mechanical project engineer

2. What construction tasks are you currently involved on construction site?
Install plant room pipe work, design and installation management

3. What construction information do you need at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	X
Equipment Information	X	Progress Information	X
Design Clarification	X	Construction Methods	X
Sub-contractor Information	X	Labour Information	X
Quality Information	X	Safety Information	X
Site Visit Record			

Where do you receive these kinds of information from?
People (sub-contractors, material suppliers)
Computer System
Document in site office

4. What construction information do you collect at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	X
Equipment Information	X	Progress Information	X
Design Clarification	X	Construction Methods	
Sub-contractor Information		Labour Information	
Quality Information		Safety Information	
Site Visit Record			

Where do you transfer these kinds of information to?
People, (design consultant)
Computer System
Document in site office

5. How do you process construction information at field (outside site office) (Please tick appropriate box)?

View	X	Edit	X	Draw	X	Mark Up	X	Write	X
Update	X	Check	X	Clarify	X	Collect Data			

Interviews

1. What is your role and responsibilities in this project?
Senior procurement manger

2. What construction tasks are you currently involved on construction site?
Sub-contract procurement and built material procurement,

3. What construction information do you need at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	X
Equipment Information		Progress Information	
Design Clarification	X	Construction Methods	X
Sub-contractor Information	X	Labour Information	
Quality Information	X	Safety Information	X
Site Visit Record			

Where do you receive these kinds of information from?
People (construction manager, design manager, planning manager)
Computer System
Document in site office

4. What construction information do you collect at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	X
Equipment Information		Progress Information	
Design Clarification	X	Construction Methods	X
Sub-contractor Information	X	Labour Information	
Quality Information	X	Safety Information	X
Site Visit Record			

Where do you transfer these kinds of information to?
People, (sub-contractor, suppliers)
Computer System
Document in site office

5. How do you process construction information at field (outside site office) (Please tick appropriate box)?

View	X	Edit		Draw		Mark Up	X	Write	X
Update	X	Check	X	Clarify	X	Collect Data			

Interviews

1. What is your role and responsibilities in this project?
Floor manager

2. What construction tasks are you currently involved on construction site?
Supervise trades and sub-trades to progress works on level 4

3. What construction information do you need at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	X
Equipment Information		Progress Information	X
Design Clarification	X	Construction Methods	X
Sub-contractor Information	X	Labour Information	X
Quality Information	X	Safety Information	X
Site Visit Record			

Where do you receive these kinds of information from?
Computer System
Document in site office

4. What construction information do you collect at field (outside site office) for above tasks? (Please tick appropriate box)

Drawings	X	Material Information	X
Equipment Information		Progress Information	X
Design Clarification	X	Construction Methods	X
Sub-contractor Information	X	Labour Information	X
Quality Information	X	Safety Information	X
Site Visit Record			

Where do you transfer these kinds of information to?
Computer System
Document in site office

5. How do you process construction information at field (outside site office) (Please tick appropriate box)?

View	X	Edit		Draw		Mark Up	X	Write	
Update	X	Check	X	Clarify	X	Collect Data	X		

System Variables: -

ext_ref : null
externalID : 0
Email Address : null
Email List Code : null
Time Taken : 3079 seconds
Duplicate : false
Timestamp : 2005-08-06 17:12:03.0
IP Address : 80.47.162.125
Geo Coding :
Country : null
Region : null
City : null
DMA Code : null
Area Code : null

A Survey of Construction Site Information Access

You are invited to participate in my survey of construction site information management. This survey is part of a doctoral research project at **University of Newcastle upon Tyne.** In this survey, approximately 1000 people will be asked to complete a questionnaire that asks questions about construction site information needs, the nature of that information, onsite communication approaches, and the experience of using mobile computing. It will take approximately 20-30 minutes to complete the questionnaire.

Your participation in this study is completely voluntary. There are no foreseeable risks associated with this project. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point. It is very important for us to learn your opinions.Your survey responses will be stricly confidential and data from this research will be used only for academic purposes. Your information will be coded and will remain confidential.

If you have questions at any time about the survey or the procedures, you may contact:

Yuan Chen, Postgraduate Research, School of Architecture, Planning and Landscape, University of Newcastle upon Tyne, Claremont Tower, Claremont Road, Newcastle upon Tyne, NE1 7RU
Dr John M. Kamara, Architectural Informatics Group, School of Architecture, Planning and Landscape, University of Newcastle upon Tyne, Claremont Tower (4th Floor, Room 421), Newcastle upon Tyne, NE1 7RU

Thank you very much for your time and support. Please start with the survey now by clicking on the **Continue** button below.

BACKGROUND INFORMATION

1.Your details

What is your Job Title in your organisation?

Project Manager

How long (in months) have you worked in this organisation?

25years

How long (in months) have you worked elsewhere in the construction industry?

288

If you want to have a copy of the research report, Please leave your email address here:

2. Please complete the following assessment of your current computer skills.

	Excellent	Good	Basic	Poor	None
Ability to use mouse and keyboard	○	○	○	◉	○
Ability to use a word processing software	○	○	○	◉	○
Ability to use Windows or other operating systems (Linux, Mac, NT)	○	○	○	○	◉
Ability to use Microsoft Office (eg. Word, Excel, Outlook, PowerPoint)	○	○	○	◉	○
Ability to use Internet	○	○	○	◉	○
Ability to use Email	○	○	◉	○	○
Ability to use Database	○	○	○	◉	○
Ability to Mobile Devices (eg. Laptop, Palmtop, PDA)	○	○	○	○	◉
Ability to use specialized software (eg. AutoCAD, project management applications)	○	○	○	○	◉
Ability to develop and program systems	○	○	○	○	◉

SPECIFIC PROJECTS

3. Please complete the following questions to describe the last project that you have been involved.

The type of project:

◉ Residential project
○ Commercial project
○ Institutional project
○ Industrialproject
○ Highway project
○ Heavy Project
○ Other (Please specify)

Project value (millions of pounds):

○ Under 1m
○ 1-5m
○ 6-10m
◉ Over 10m

Project duration (in years):

○ 1 year
○ 2 years
○ 3 years
○ 4 years
○ 5 years
◉ Over 5 years

Project construction sites:

- ☐ Multi-site project
- ☐ Small-size construction site
- ☑ Medium-size construction site
- ☐ Large-size construction site
- ☐ Other (Please specify)

On average, how many hours per week did you spend on project work sites (out site offices)?

- ○ 0 hour
- ○ 1-5 hours
- ○ 6-10 hours
- ○ 11-15 hours
- ○ 16-20 hours
- ◉ Over 20 hours
- ○ Other

What types of mobile devices did you use in this project?

- ☑ Desktop with connection to networks
- ☐ Palm computer without connection to networks
- ☐ Palm computer with connection to networks
- ☐ Laptop computer without connection to networks
- ☐ Laptop computer with connection to networks
- ☐ Other

What tasks did you use mobile computing to perform in this project (multi-option)?

- ☑ None
- ☐ Safety management
- ☐ Progress management
- ☐ Review drawings
- ☐ Review specifications
- ☐ Cost and price management
- ☐ Labour management
- ☐ Material management
- ☐ Equipment management
- ☐ Construction method
- ☐ Other

CONSTRUCTION INFORMATION

4. For the project described in section 3, please select the types of construction information that you received on construction sites, and answer the corresponding questions.

Please select the types of construction information that you received on construction sites.

- ☑ Drawings

- ☐ Material management information
- ☐ Equipment management information
- ☑ Contract information
- ☑ Progress management information
- ☑ Safety management information
- ☑ Sub-contractor information
- ☑ Design clarifications
- ☐ Construction and engineering methods
- ☑ Specification
- ☑ Labour information
- ☑ Quality control information
- ☐ Other (Please specify)

Please tick appropriated boxes (multi-option) to indicate the formats of each information that you received on construction sites.

	Text	Graphic	Form	Image	Verbal	Other
Drawings	☑	☑	☐	☐	☑	☐
Material Management Information	☑	☐	☐	☐	☑	☐
Equipment Management Information	☐	☐	☐	☐	☐	☐
Contract Information	☑	☑	☐	☐	☑	☐
Progress Management Information	☑	☑	☐	☐	☐	☐
Safety Management Information	☑	☑	☐	☑	☑	☐
Sub-contractor Information	☑	☑	☐	☑	☑	☐
Design Clarifications	☑	☑	☐	☐	☐	☐
Construction and Engineering Methods	☑	☑	☐	☑	☑	☐
Specification	☑	☐	☐	☐	☐	☐
Labour Information	☑	☐	☐	☐	☑	☐
Quality Control Information	☑	☑	☐	☐	☑	☐

Please tick appropriated boxes (multi-option) to indicate that from who or from where you received each information on construction sites.

	Supervisor	Client	Consultant	Design Team	Sub-Constructor	Engineer	Supplier	Project Manager	Quantity Surveyor	Other
Drawings	☐	☐	☑	☑	☑	☐	☐	☑	☐	☐
Material Management Information	☐	☑	☑	☐	☐	☐	☐	☐	☐	☐
Equipment Management Information	☐	☐	☑	☑	☐	☐	☐	☑	☑	☐
Contract Information	☐	☑	☑	☑	☑	☑	☑	☑	☑	☐
Progress Management Information	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐
Safety Management Information	☐	☑	☑	☑	☑	☑	☑	☑	☐	☐
Sub-contractor	☐	☐	☐	☐	☑	☐	☐	☑	☐	☐

Information										
Design Clarifications	☐	☐	☑	☑	☐	☐	☐	☐	☑	☐
Construction and Engineering Methods	☐	☐	☐	☑	☐	☑	☐	☐	☐	☐
Specification	☐	☑	☐	☑	☐	☑	☐	☐	☐	☐
Labour Information	☑	☐	☐	☐	☑	☐	☐	☐	☐	☐
Quality Control Information	☐	☐	☐	☑	☐	☑	☐	☑	☐	☐

Please tick appropriated boxes (multi-option) to indicate the **Transfer Mediums** (How was this information transfered to you?) for each information that you received on construction sites.

	Meeting	**One-to-one Pass**	**Fax**	**Phone**	**Email**	**Intra/ Extranet**	**Post**	**Transfer of computer discs**	**Other**
Drawings	☑	☑	☑	☑	☐	☐	☑	☐	☑
Material Management Information	☑	☑	☐	☑	☐	☐	☑	☐	☐
Equipment Management Information	☑	☑	☐	☑	☐	☐	☑	☐	☐
Contract Information	☑	☑	☐	☑	☐	☐	☑	☐	☐
Progress Management Information	☑	☐	☐	☐	☐	☐	☐	☐	☐
Safety Management Information	☑	☐	☐	☑	☐	☐	☑	☐	☑
Sub-contractor Information	☑	☐	☐	☑	☐	☐	☑	☐	☑
Design Clarifications	☑	☑	☐	☑	☐	☐	☑	☐	☑
Construction and Engineering Methods	☑	☐	☐	☑	☐	☐	☑	☐	☐
Specification	☑	☐	☐	☑	☐	☐	☐	☐	☐
Labour Information	☑	☐	☐	☑	☐	☐	☑	☐	☐
Quality Control Information	☑	☑	☐	☑	☐	☐	☑	☐	☐

Please tick appropriated boxes (multi-option) to indicate that **how you accessed each information on work sites (out site office)?**

	Make Phone Call	**Retrieve from Memory**	**Retrieve from Notebook**	**Take Document on Hand**	**Other**
Drawings	☑	☑	☑	☑	☐
Material Management Information	☑	☑	☑	☑	☐
Equipment Management Information	☑	☐	☐	☐	☐
Contract Information	☑	☑	☑	☑	☐
Progress Management Information	☑	☑	☑	☑	☐
Safety Management Information	☑	☑	☑	☑	☐
Sub-contractor Information	☑	☑	☑	☑	☐
Design Clarifications	☑	☐	☐	☐	☐
Construction and Engineering Methods	☑	☑	☑	☐	☐
Specification	☑	☑	☐	☐	☐

Labour Information	☑	☑	☑	☐	☐
Quality Control Information	☐	☑	☑	☐	☐

5. For the project described in section 3, please select the types of construction information that you transfer from construction sites, and answer the corresponding questions.

Please select the types of construction information that you transfer from construction sites.

- ☑ Request for information
- ☐ Material management update
- ☐ Equipment management update
- ☑ Schedule update
- ☑ Progress update
- ☑ Site visit record
- ☑ Production report
- ☑ Sub-contractor performance report
- ☑ Quality report
- ☑ Labour output
- ☑ Safety record
- ☑ Other (Please specify) weather reports

Please tick appropriated boxes (multi-option) to indicate the formats of each information that you transfered from construction sites.

	Text	Graphic	Form	Image	Verbal	Other
Request for Information	☑	☐	☐	☑	☑	☐
Material Management Update	☐	☐	☐	☐	☐	☐
Equipment Management Update	☐	☐	☐	☐	☐	☐
Schedule Update	☑	☐	☐	☑	☑	☐
Progress Update	☑	☐	☐	☑	☑	☐
Site Visit Record	☑	☐	☐	☐	☑	☐
Production Report	☑	☐	☐	☐	☑	☐
Sub-contractor Performance report	☑	☐	☐	☐	☑	☐
Quality Report	☑	☐	☐	☐	☑	☐
Labour Output Record	☑	☐	☐	☐	☑	☐
Safety Record	☑	☐	☐	☐	☑	☐

Please tick appropriated boxes (multi-option) to indicate that on construction sites who or where you sent each information to.

	Supervisor	Client	Consultant	Design Team	Sub-contractor	Engineer	Supplier	Project Manager	Quantity surveyor	Other
Request for Information	☑	☑	☑	☑	☐	☐	☐	☐	☑	☐
Material Management Update	☑	☑	☑	☑	☐	☐	☐	☐	☑	☐
Equipment Management Update	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Schedule Update	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐

Progress Update	☐	☑	☐	☑	☐	☐	☐	☑	☑	☐
Site Visit Record	☑	☑	☐	☑	☐	☐	☐	☐	☐	☐
Production Report	☑	☑	☐	☑	☐	☐	☐	☐	☐	☐
Sub-contractor Performance report	☑	☑	☐	☑	☐	☐	☐	☑	☑	☐
Quality Report	☐	☑	☐	☑	☐	☐	☐	☐	☑	☐
Labour Output Record	☐	☑	☐	☑	☐	☐	☐	☑	☐	☐
Safety Record	☑	☑	☑	☑	☐	☑	☐	☑	☐	☐

Please tick appropriated boxes (multi-option) to indicate the **Transfer Mediums** (How did you transfer this information?) for each information that you transferred on construction sites.

	Meeting	One-to-One Pass	Fax	Phone	Email	Intra/ Extranet	Post	Transfer of Computer Discs	Other
Request for Information	☑	☐	☐	☑	☐	☐	☑	☐	☐
Material Management Update	☑	☐	☐	☑	☐	☐	☑	☐	☐
Equipment Management Update	☐	☐	☐	☐	☐	☐	☐	☐	☐
Schedule Update	☑	☐	☐	☑	☐	☐	☑	☐	☐
Progress Update	☑	☐	☐	☑	☐	☐	☑	☐	☐
Site Visit Record	☑	☐	☐	☑	☐	☐	☑	☐	☐
Production Report	☑	☐	☐	☑	☐	☐	☑	☐	☐
Sub-contractor Performance report	☑	☐	☐	☑	☐	☐	☑	☐	☐
Quality Report	☑	☐	☐	☑	☐	☐	☑	☐	☐
Labour Output Record	☑	☐	☐	☑	☐	☐	☑	☐	☐
Safety Record	☑	☐	☐	☑	☐	☐	☑	☐	☐

Please tick appropriated boxes (multi-option) to indicate that **how you collected each information on work sites (out site office)?**

	Use Mobile devices	Remember in Memory	Record on Notebook	Fill Standard Form	Other
Request for Information	☐	☑	☑	☑	☐
Material Management Update	☐	☑	☑	☐	☐
Equipment Management Update	☐	☑	☑	☐	☐
Schedule Update	☐	☑	☑	☑	☐
Progress Update	☐	☑	☑	☑	☐
Site Visit Record	☐	☑	☑	☑	☐
Production Report	☐	☑	☑	☑	☐
Sub-contractor Performance report	☐	☑	☑	☐	☐
Quality Report	☐	☑	☑	☑	☐
Labour Output Record	☐	☑	☑	☑	☐

Safety Record	☐	☑	☑	☑	☐

COMMENTS AND SUGGESTIONS

6. How do you think the current approaches of construction information communication on construction sites?

7. Please list problems encountered in the retrieve, collection, and transmission of construction information on construction sites.

8. What improvements, do you think, can be made in transmission of construction site information?

more use of computers and
tech knowledge that is
becoming availible

9. Do you think that the retrieving, collecting and transmitting information on construction work site information can benefit from the use of mobile devices and wireless networks? Why?

yes
information can be delivered
more quickly and you have a
perminant record of
information sent

10. Do you think that there are potential barriers in the use of mobile devices in construction sites? If yes, what barriers? If no, Why?

yes
more training has to be
given from the top to the
bottom, to create a
competant team

11. What aspect of construction site information communication, do you think, can benefit the most from mobile technologies?

senior and middle management

System Variables: -

ext_ref : null
externalID : 0
Email Address : null
Email List Code : null
Time Taken : 1279 seconds
Duplicate : false
Timestamp : 2005-07-28 04:21:33.0
IP Address : 151.133.226.94
Geo Coding :
Country : null
Region : null
City : null
DMA Code : null
Area Code : null

A Survey of Construction Site Information Access

You are invited to participate in my survey of construction site information management. This survey is part of a doctoral research project at **University of Newcastle upon Tyne.** In this survey, approximately 1000 people will be asked to complete a questionnaire that asks questions about construction site information needs, the nature of that information, onsite communication approaches, and the experience of using mobile computing. It will take approximately 20-30 minutes to complete the questionnaire.

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If you have questions at any time about the survey or the procedures, you may contact:

Yuan Chen, Postgraduate Research, School of Architecture, Planning and Landscape, University of Newcastle upon Tyne, Claremont Tower, Claremont Road, Newcastle upon Tyne, NE1 7RU
Dr John M. Kamara, Architectural Informatics Group, School of Architecture, Planning and Landscape, University of Newcastle upon Tyne, Claremont Tower (4th Floor, Room 421), Newcastle upon Tyne, NE1 7RU

Thank you very much for your time and support. Please start with the survey now by clicking on the **Continue** button below.

BACKGROUND INFORMATION

1.Your details

What is your Job Title in your organisation?

Quantity Surveyor

How long (in months) have you worked in this organisation?

48

How long (in months) have you worked elsewhere in the construction industry?

240

If you want to have a copy of the research report, Please leave your email address here:

2. Please complete the following assessment of your current computer skills.

	Excellent	Good	Basic	Poor	None
Ability to use mouse and keyboard	◉	○	○	○	○
Ability to use a word processing software	◉	○	○	○	○
Ability to use Windows or other operating systems (Linux, Mac, NT)	◉	○	○	○	○
Ability to use Microsoft Office (eg. Word, Excel, Outlook, PowerPoint)	◉	○	○	○	○
Ability to use Internet	◉	○	○	○	○
Ability to use Email	◉	○	○	○	○
Ability to use Database	◉	○	○	○	○
Ability to Mobile Devices (eg. Laptop, Palmtop, PDA)	◉	○	○	○	○
Ability to use specialized software (eg. AutoCAD, project management applications)	◉	○	○	○	○
Ability to develop and program systems	○	○	○	◉	○

SPECIFIC PROJECTS

3. Please complete the following questions to describe the last project that you have been involved.

The type of project:

- ◉ Residential project
- ○ Commercial project
- ○ Institutional project
- ○ Industrialproject
- ○ Highway project
- ○ Heavy Project
- ○ Other (Please specify)

Project value (millions of pounds):

- ◉ Under 1m
- ○ 1-5m
- ○ 6-10m
- ○ Over 10m

Project duration (in years):

- ◉ 1 year
- ○ 2 years
- ○ 3 years
- ○ 4 years
- ○ 5 years
- ○ Over 5 years

Project construction sites:

- [ ] Multi-site project
- [x] Small-size construction site
- [ ] Medium-size construction site
- [ ] Large-size construction site
- [ ] Other (Please specify) ______________________

On average, how many hours per week did you spend on project work sites (out site offices)?

- ○ 0 hour
- ◉ 1-5 hours
- ○ 6-10 hours
- ○ 11-15 hours
- ○ 16-20 hours
- ○ Over 20 hours
- ○ Other ______________________

What types of mobile devices did you use in this project?

- [ ] Desktop with connection to networks
- [ ] Palm computer without connection to networks
- [ ] Palm computer with connection to networks
- [x] Laptop computer without connection to networks
- [ ] Laptop computer with connection to networks
- [ ] Other ______________________

What tasks did you use mobile computing to perform in this project (multi-option)?

- [ ] None
- [ ] Safety management
- [x] Progress management
- [ ] Review drawings
- [x] Review specifications
- [x] Cost and price management
- [ ] Labour management
- [ ] Material management
- [ ] Equipment management
- [ ] Construction method
- [ ] Other ______________________

CONSTRUCTION INFORMATION

4. For the project described in section 3, please select the types of construction information that you received on construction sites, and answer the corresponding questions.

Please select the types of construction information that you **received on construction sites.**

- [x] Drawings

- ☐ Material management information
- ☐ Equipment management information
- ☑ Contract information
- ☑ Progress management information
- ☐ Safety management information
- ☑ Sub-contractor information
- ☐ Design clarifications
- ☐ Construction and engineering methods
- ☑ Specification
- ☐ Labour information
- ☐ Quality control information
- ☐ Other (Please specify)

Please tick appropriated boxes **(multi-option)** to indicate the **formats** of each information that you received on construction sites.

	Text	Graphic	Form	Image	Verbal	Other
Drawings	☐	☑	☐	☐	☐	☐
Material Management Information	☑	☐	☐	☐	☐	☐
Equipment Management Information	☑	☐	☐	☐	☐	☐
Contract Information	☑	☐	☐	☐	☐	☐
Progress Management Information	☐	☑	☐	☐	☐	☐
Safety Management Information	☑	☐	☐	☐	☐	☐
Sub-contractor Information	☑	☐	☐	☐	☐	☐
Design Clarifications	☑	☑	☑	☐	☐	☐
Construction and Engineering Methods	☑	☐	☐	☐	☐	☐
Specification	☑	☐	☐	☐	☐	☐
Labour Information	☑	☐	☐	☐	☐	☐
Quality Control Information	☑	☐	☐	☐	☐	☐

Please tick appropriated boxes **(multi-option)** to indicate that **from who or from where** you received each information on construction sites.

	Supervisor	Client	Consultant	Design Team	Sub-Constructor	Engineer	Supplier	Project Manager	Quantity Surveyor	Other
Drawings	☐	☐	☐	☑	☑	☑	☐	☐	☐	☐
Material Management Information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Equipment Management Information	☐	☐	☐	☐	☑	☐	☑	☐	☐	☐
Contract Information	☐	☐	☑	☐	☑	☐	☑	☐	☐	☐
Progress Management Information	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety Management Information	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sub-contractor	☐	☐	☐	☐	☑	☐	☑	☐	☐	☐

Information										
Design Clarifications	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐
Construction and Engineering Methods	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Specification	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Labour Information	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Quality Control Information	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please tick appropriated boxes **(multi-option)** to indicate the **Transfer Mediums** (How was this information transfered to you?) for each information that you received on construction sites.

	Meeting	**One-to-one Pass**	**Fax**	**Phone**	**Email**	**Intra/ Extranet**	**Post**	**Transfer of computer discs**	**Other**
Drawings	☑	☐	☐	☐	☐	☐	☑	☑	☐
Material Management Information	☐	☐	☑	☑	☑	☐	☐	☐	☐
Equipment Management Information	☐	☐	☑	☑	☐	☐	☐	☐	☐
Contract Information	☑	☑	☐	☑	☑	☐	☐	☐	☐
Progress Management Information	☑	☑	☐	☑	☐	☐	☐	☐	☐
Safety Management Information	☑	☑	☐	☑	☐	☐	☐	☐	☐
Sub-contractor Information	☑	☐	☑	☑	☐	☐	☐	☐	☐
Design Clarifications	☑	☑	☐	☑	☐	☐	☐	☑	☐
Construction and Engineering Methods	☑	☐	☐	☐	☐	☐	☐	☐	☐
Specification	☑	☐	☑	☑	☐	☐	☐	☐	☐
Labour Information	☑	☑	☐	☐	☐	☐	☐	☐	☐
Quality Control Information	☑	☑	☐	☐	☐	☐	☐	☐	☐

Please tick appropriated boxes **(multi-option)** to indicate that **how you accessed each information on work sites (out site office)?**

	Make Phone Call	**Retrieve from Memory**	**Retrieve from Notebook**	**Take Document on Hand**	**Other**
Drawings	☑	☐	☐	☑	☐
Material Management Information	☑	☐	☐	☑	☐
Equipment Management Information	☐	☐	☑	☑	☐
Contract Information	☐	☐	☐	☑	☐
Progress Management Information	☑	☐	☑	☑	☐
Safety Management Information	☑	☐	☑	☐	☐
Sub-contractor Information	☑	☐	☑	☐	☐
Design Clarifications	☑	☐	☑	☑	☐
Construction and Engineering Methods	☐	☑	☐	☐	☐
Specification	☑	☑	☐	☐	☐

Labour Information	☑	☑	☐	☐	☐
Quality Control Information	☑	☑	☐	☐	☐

5. For the project described in section 3, please select the types of construction information that you transfer from construction sites, and answer the corresponding questions.

Please select the types of construction information that you **transfer from construction sites.**

- ☑ Request for information
- ☑ Material management update
- ☐ Equipment management update
- ☑ Schedule update
- ☑ Progress update
- ☑ Site visit record
- ☐ Production report
- ☑ Sub-contractor performance report
- ☐ Quality report
- ☑ Labour output
- ☐ Safety record
- ☐ Other (Please specify)

Please tick appropriated boxes **(multi-option)** to indicate the **formats** of each information that you transfered from construction sites.

	Text	Graphic	Form	Image	Verbal	Other
Request for Information	☑	☑	☐	☐	☑	☐
Material Management Update	☑	☐	☐	☐	☑	☐
Equipment Management Update	☑	☐	☐	☐	☑	☐
Schedule Update	☑	☑	☐	☐	☐	☐
Progress Update	☑	☑	☐	☐	☑	☐
Site Visit Record	☑	☐	☐	☐	☐	☐
Production Report	☑	☐	☐	☐	☐	☐
Sub-contractor Performance report	☑	☐	☐	☐	☐	☐
Quality Report	☑	☐	☐	☐	☐	☐
Labour Output Record	☑	☐	☐	☐	☐	☐
Safety Record	☑	☐	☐	☐	☐	☐

Please tick appropriated boxes **(multi-option)** to indicate that on construction sites **who or where** you sent each information to.

	Supervisor	Client	Consultant	Design Team	Sub-contractor	Engineer	Supplier	Project Manager	Quantity surveyor	Other
Request for Information	☑	☐	☐	☑	☑	☐	☑	☐	☐	☐
Material Management Update	☑	☐	☐	☐	☐	☐	☑	☐	☐	☐
Equipment Management Update	☑	☐	☐	☐	☑	☐	☑	☐	☐	☐
Schedule Update	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐

Progress Update	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Site Visit Record	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Production Report	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sub-contractor Performance report	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Quality Report	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Labour Output Record	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐
Safety Record	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please tick appropriated boxes (multi-option) to indicate the **Transfer Mediums** (How did you transfer this information?) for each information that you transferred on construction sites.

	Meeting	**One-to-One Pass**	**Fax**	**Phone**	**Email**	**Intra/ Extranet**	**Post**	**Transfer of Computer Discs**	**Other**
Request for Information	☑	☑	☑	☐	☑	☐	☐	☐	☐
Material Management Update	☑	☐	☐	☑	☑	☐	☐	☐	☐
Equipment Management Update	☑	☐	☐	☑	☐	☐	☐	☐	☐
Schedule Update	☑	☑	☐	☑	☐	☐	☐	☐	☐
Progress Update	☐	☐	☐	☐	☐	☐	☐	☐	☐
Site Visit Record	☑	☑	☑	☑	☐	☐	☐	☐	☐
Production Report	☑	☑	☐	☐	☐	☐	☐	☐	☐
Sub-contractor Performance report	☑	☑	☐	☐	☐	☐	☐	☐	☐
Quality Report	☑	☑	☐	☐	☐	☐	☐	☐	☐
Labour Output Record	☑	☑	☐	☐	☐	☐	☐	☐	☐
Safety Record	☑	☑	☐	☐	☐	☐	☐	☐	☐

Please tick appropriated boxes (multi-option) to indicate that **how you collected each information on work sites (out site office)?**

	Use Mobile devices	**Remember in Memory**	**Record on Notebook**	**Fill Standard Form**	**Other**
Request for Information	☐	☐	☑	☑	☐
Material Management Update	☐	☐	☑	☐	☐
Equipment Management Update	☐	☐	☑	☑	☐
Schedule Update	☐	☐	☑	☐	☐
Progress Update	☐	☐	☑	☐	☐
Site Visit Record	☐	☐	☑	☐	☐
Production Report	☐	☐	☑	☐	☐
Sub-contractor Performance report	☐	☐	☑	☐	☐
Quality Report	☐	☐	☑	☐	☐
Labour Output Record	☐	☐	☐	☑	☐

Safety Record ☐ ☐ ☐ ☑ ☐

COMMENTS AND SUGGESTIONS

6. How do you think the current approaches of construction information communication on construction sites?

For small project is still predominately traditional.

7. Please list problems encountered in the retrieve, collection, and transmission of construction information on construction sites.

Problems associated with traditional ways of retrieving and transmitting information.

8. What improvements, do you think, can be made in transmission of construction site information?

Encourage small firms to uses current technology.

9. Do you think that the retrieving, collecting and transmitting information on construction work site information can benefit from the use of mobile devices and wireless networks? Why?

yes

10. Do you think that there are potential barriers in the use of mobile devices in construction sites? If yes, what barriers? If no, Why?

Yes, technology need to be tried first.

11. What aspect of construction site information communication, do you think, can benefit the most from mobile technologies?

All area because everything depends on data.

System Variables: -

ext_ref : null
externalID : 0
Email Address : null
Email List Code : null
Time Taken : 1629 seconds
Duplicate : false
Timestamp : 2005-10-31 05:23:25.0
IP Address : 195.92.247.214
Geo Coding :
Country : null
Region : null
City : null
DMA Code : null
Area Code : null

A Survey of Construction Site Information Access

You are invited to participate in my survey of construction site information management. This survey is part of a doctoral research project at **University of Newcastle upon Tyne.** In this survey, approximately 1000 people will be asked to complete a questionnaire that asks questions about construction site information needs, the nature of that information, onsite communication approaches, and the experience of using mobile computing. It will take approximately 20-30 minutes to complete the questionnaire.

Your participation in this study is completely voluntary. There are no foreseeable risks associated with this project. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point. It is very important for us to learn your opinions.Your survey responses will be stricly confidential and data from this research will be used only for academic purposes. Your information will be coded and will remain confidential.

If you have questions at any time about the survey or the procedures, you may contact:

Yuan Chen, Postgraduate Research, School of Architecture, Planning and Landscape, University of Newcastle upon Tyne, Claremont Tower, Claremont Road, Newcastle upon Tyne, NE1 7RU
Dr John M. Kamara, Architectural Informatics Group, School of Architecture, Planning and Landscape, University of Newcastle upon Tyne, Claremont Tower (4th Floor, Room 421), Newcastle upon Tyne, NE1 7RU

Thank you very much for your time and support. Please start with the survey now by clicking on the **Continue** button below.

BACKGROUND INFORMATION

1.Your details

What is your Job Title in your organisation?

Regional Design Manager

How long (in months) have you worked in this organisation?

210

How long (in months) have you worked elsewhere in the construction industry?

168

If you want to have a copy of the research report, Please leave your email address here:

2. Please complete the following assessment of your current computer skills.

	Excellent	Good	Basic	Poor	None
Ability to use mouse and keyboard	○	◉	○	○	○
Ability to use a word processing software	○	◉	○	○	○
Ability to use Windows or other operating systems (Linux, Mac, NT)	○	◉	○	○	○
Ability to use Microsoft Office (eg. Word, Excel, Outlook, PowerPoint)	○	◉	○	○	○
Ability to use Internet	○	◉	○	○	○
Ability to use Email	○	○	◉	○	○
Ability to use Database	○	○	○	◉	○
Ability to Mobile Devices (eg. Laptop, Palmtop, PDA)	○	○	◉	○	○
Ability to use specialized software (eg. AutoCAD, project management applications)	○	○	◉	○	○
Ability to develop and program systems	○	○	○	○	◉

SPECIFIC PROJECTS

3. Please complete the following questions to describe the last project that you have been involved.

The type of project:

○ Residential project
◉ Commercial project
○ Institutional project
○ Industrialproject
○ Highway project
○ Heavy Project
○ Other (Please specify)

Project value (millions of pounds):

○ Under 1m
○ 1-5m
○ 6-10m
◉ Over 10m

Project duration (in years):

○ 1 year
◉ 2 years
○ 3 years
○ 4 years
○ 5 years
○ Over 5 years

Project construction sites:

- ☐ Multi-site project
- ☐ Small-size construction site
- ☐ Medium-size construction site
- ☑ Large-size construction site
- ☐ Other (Please specify)

On average, how many hours per week did you spend on project work sites (out site offices)?

- ○ 0 hour
- ○ 1-5 hours
- ○ 6-10 hours
- ○ 11-15 hours
- ○ 16-20 hours
- ◉ Over 20 hours
- ○ Other

What types of mobile devices did you use in this project?

- ☐ Desktop with connection to networks
- ☐ Palm computer without connection to networks
- ☐ Palm computer with connection to networks
- ☐ Laptop computer without connection to networks
- ☑ Laptop computer with connection to networks
- ☐ Other

What tasks did you use mobile computing to perform in this project (multi-option)?

- ☐ None
- ☐ Safety management
- ☐ Progress management
- ☐ Review drawings
- ☐ Review specifications
- ☐ Cost and price management
- ☐ Labour management
- ☐ Material management
- ☐ Equipment management
- ☐ Construction method
- ☑ Other Risk Management Design management

CONSTRUCTION INFORMATION

4. For the project described in section 3, please select the types of construction information that you received on construction sites, and answer the corresponding questions.

Please select the types of construction information that you received on construction sites.

- ☑ Drawings

☐ Material management information

☐ Equipment management information

☑ Contract information

☐ Progress management information

☐ Safety management information

☑ Sub-contractor information

☑ Design clarifications

☐ Construction and engineering methods

☑ Specification

☐ Labour information

☐ Quality control information

☐ Other (Please specify)

Please tick appropriated boxes (multi-option) to indicate the **formats** of each information that you received on construction sites.

	Text	Graphic	Form	Image	Verbal	Other
Drawings	☐	☑	☐	☐	☐	☐
Material Management Information	☑	☐	☐	☐	☑	☐
Equipment Management Information	☑	☐	☐	☐	☑	☐
Contract Information	☑	☐	☐	☐	☐	☐
Progress Management Information	☑	☐	☐	☐	☐	☐
Safety Management Information	☑	☑	☐	☐	☐	☐
Sub-contractor Information	☑	☐	☐	☐	☑	☐
Design Clarifications	☑	☑	☑	☐	☐	☐
Construction and Engineering Methods	☑	☐	☐	☐	☑	☐
Specification	☑	☐	☐	☐	☐	☐
Labour Information	☑	☐	☐	☐	☑	☐
Quality Control Information	☑	☐	☐	☐	☐	☐

Please tick appropriated boxes (multi-option) to indicate that **from who or from where** you received each information on construction sites.

	Supervisor	Client	Consultant	Design Team	Sub-Constructor	Engineer	Supplier	Project Manager	Quantity Surveyor	Other
Drawings	☐	☐	☐	☑	☑	☐	☐	☐	☐	☐
Material Management Information	☐	☐	☐	☐	☐	☐	☑	☑	☑	☐
Equipment Management Information	☐	☐	☐	☐	☐	☐	☑	☑	☑	☐
Contract Information	☐	☑	☐	☑	☐	☐	☐	☐	☑	☐
Progress Management Information	☑	☐	☐	☐	☐	☐	☐	☑	☐	☐
Safety Management Information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sub-contractor	☐	☐	☐	☐	☐	☐	☐	☐	☑	☐

Information										
Design Clarifications	☐	☑	☑	☑	☐	☐	☐	☐	☐	☐
Construction and Engineering Methods	☐	☐	☐	☑	☑	☑	☐	☐	☐	☐
Specification	☐	☐	☑	☑	☐	☐	☐	☐	☐	☐
Labour Information	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Quality Control Information	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please tick appropriated boxes (multi-option) to indicate the **Transfer Mediums** (How was this information transfered to you?) for each information that you received on construction sites.

	Meeting	**One-to-one Pass**	**Fax**	**Phone**	**Email**	**Intra/ Extranet**	**Post**	**Transfer of computer discs**	**Other**
Drawings	☑	☐	☐	☐	☐	☐	☑	☑	☐
Material Management Information	☐	☐	☐	☐	☑	☐	☑	☐	☐
Equipment Management Information	☐	☐	☐	☐	☑	☐	☑	☐	☐
Contract Information	☐	☑	☐	☐	☑	☑	☐	☐	☐
Progress Management Information	☐	☑	☐	☐	☑	☐	☐	☐	☐
Safety Management Information	☐	☑	☐	☐	☑	☐	☑	☐	☐
Sub-contractor Information	☑	☑	☐	☐	☑	☐	☐	☐	☐
Design Clarifications	☑	☑	☑	☑	☑	☐	☐	☐	☐
Construction and Engineering Methods	☑	☑	☐	☐	☑	☐	☐	☐	☐
Specification	☐	☐	☐	☐	☑	☑	☑	☐	☐
Labour Information	☑	☑	☑	☑	☑	☐	☐	☐	☐
Quality Control Information	☑	☑	☑	☑	☑	☐	☐	☐	☐

Please tick appropriated boxes (multi-option) to indicate that **how you accessed each information on work sites (out site office)?**

	Make Phone Call	**Retrieve from Memory**	**Retrieve from Notebook**	**Take Document on Hand**	**Other**
Drawings	☐	☑	☐	☑	☐
Material Management Information	☐	☑	☐	☑	☐
Equipment Management Information	☐	☑	☐	☑	☐
Contract Information	☐	☑	☐	☑	☐
Progress Management Information	☐	☑	☐	☑	☐
Safety Management Information	☐	☑	☐	☑	☐
Sub-contractor Information	☑	☑	☐	☑	☐
Design Clarifications	☑	☑	☐	☑	☐
Construction and Engineering Methods	☐	☑	☐	☑	☐
Specification	☐	☑	☐	☑	☐

Labour Information	☐	☑	☐	☑	☐
Quality Control Information	☐	☑	☐	☑	☐

5. For the project described in section 3, please select the types of construction information that you transfer from construction sites, and answer the corresponding questions.

Please select the types of construction information that you **transfer from construction sites.**

- ☑ Request for information
- ☐ Material management update
- ☐ Equipment management update
- ☑ Schedule update
- ☐ Progress update
- ☐ Site visit record
- ☐ Production report
- ☑ Sub-contractor performance report
- ☐ Quality report
- ☐ Labour output
- ☐ Safety record
- ☐ Other (Please specify)

Please tick appropriated boxes (multi-option) to indicate the **formats** of each information that you transfered from construction sites.

	Text	Graphic	Form	Image	Verbal	Other
Request for Information	☑	☐	☐	☐	☐	☐
Material Management Update	☑	☐	☐	☐	☑	☐
Equipment Management Update	☑	☐	☐	☐	☑	☐
Schedule Update	☑	☑	☐	☐	☐	☐
Progress Update	☑	☑	☐	☐	☐	☐
Site Visit Record	☑	☐	☐	☐	☐	☐
Production Report	☑	☑	☑	☐	☐	☐
Sub-contractor Performance report	☐	☐	☑	☐	☐	☐
Quality Report	☑	☐	☑	☐	☐	☐
Labour Output Record	☑	☐	☐	☐	☑	☐
Safety Record	☑	☐	☑	☐	☑	☐

Please tick appropriated boxes (multi-option) to indicate that on construction sites **who or where** you sent each information to.

	Supervisor	Client	Consultant	Design Team	Sub-contractor	Engineer	Supplier	Project Manager	Quantity surveyor	Other
Request for Information	☐	☑	☑	☑	☐	☐	☐	☐	☐	☐
Material Management Update	☑	☐	☐	☑	☐	☐	☑	☑	☑	☐
Equipment Management Update	☐	☐	☐	☐	☑	☐	☑	☑	☐	☐
Schedule Update	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐

Progress Update	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐
Site Visit Record	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Production Report	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Sub-contractor Performance report	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Quality Report	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐
Labour Output Record	☐	☐	☐	☐	☐	☐	☐	☑	☑	☐
Safety Record	☐	☐	☐	☐	☐	☐	☐	☑	☐	☐

Please tick appropriated boxes (multi-option) to indicate the **Transfer Mediums** (How did you transfer this information?) for each information that you transferred on construction sites.

	Meeting	One-to-One Pass	Fax	Phone	Email	Intra/ Extranet	Post	Transfer of Computer Discs	Other
Request for Information	☑	☐	☐	☐	☑	☐	☐	☐	☐
Material Management Update	☐	☑	☐	☑	☑	☐	☐	☐	☐
Equipment Management Update	☐	☑	☐	☑	☑	☐	☐	☐	☐
Schedule Update	☐	☑	☐	☐	☐	☐	☐	☐	☐
Progress Update	☐	☑	☐	☐	☐	☐	☐	☐	☐
Site Visit Record	☑	☐	☐	☐	☑	☐	☐	☐	☐
Production Report	☐	☐	☐	☐	☑	☐	☑	☐	☐
Sub-contractor Performance report	☑	☐	☐	☑	☑	☑	☐	☐	☐
Quality Report	☐	☑	☐	☐	☐	☑	☐	☐	☐
Labour Output Record	☐	☑	☐	☐	☐	☑	☐	☐	☐
Safety Record	☐	☑	☐	☐	☐	☑	☐	☐	☐

Please tick appropriated boxes (multi-option) to indicate that **how you collected each information on work sites (out site office)?**

	Use Mobile devices	Remember in Memory	Record on Notebook	Fill Standard Form	Other
Request for Information	☐	☑	☐	☑	☐
Material Management Update	☐	☑	☐	☐	☐
Equipment Management Update	☐	☑	☐	☐	☐
Schedule Update	☐	☑	☐	☑	☐
Progress Update	☐	☑	☐	☑	☐
Site Visit Record	☐	☑	☐	☐	☐
Production Report	☐	☑	☐	☑	☐
Sub-contractor Performance report	☐	☑	☐	☐	☐
Quality Report	☐	☑	☐	☐	☐
Labour Output Record	☐	☑	☐	☐	☐

Safety Record ☐ ☑ ☐ ☐ ☐

COMMENTS AND SUGGESTIONS

6. How do you think the current approaches of construction information communication on construction sites?

```
Too much use of e mail and
not enough one to one
discussions.
```

7. Please list problems encountered in the retrieve, collection, and transmission of construction information on construction sites.

```
Slow speed of intranet
Too many e mails such that
managers
```

8. What improvements, do you think, can be made in transmission of construction site information?

```
Use of collaboration methods
but the intranets need to be
sized to be able to cope
with increased
electronic 'traffic'.
Too much trivia sent on e
```

9. Do you think that the retrieving, collecting and transmitting information on construction work site information can benefit from the use of mobile devices and wireless networks? Why?

```
No - on London sites too
much interference - wireless
can be less than robust.
Mobile devices are fine
between workers on site eg
crane draiver to banksman
```

10. Do you think that there are potential barriers in the use of mobile devices in construction sites? If yes, what barriers? If no, Why?

```
Theft is a problem as mobile
devices are easy to conceal.
```

11. What aspect of construction site information communication, do you think, can benefit the most from mobile technologies?

```
On site communication rather
than site office
communication
```