The University of Salford

College of Science & Technology

School of the Built Environment

Development of a Framework to Enhance Communication Practice for Site-based Construction Workers in The Kingdom of Saudi Arabia

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Declaration

I declare that the work contained in this thesis is my own original work. Where work and ideas or concepts have been taken or adapted from any source, they have been properly cited and referenced.

Abbreviations

KSA Kingdom of Saudi Arabia

ICT Information and communication technology

IT Information technology

SAGIA Saudi Arabian General Investment Authority

SR Saudi riyal

MC Mobile computing

IS Information System

MC Mobile Computing

ISM Interpretive Structural Modelling

Publications Arising from this Thesis

Conference Papers

1. Alaboud, N., & Zeeshan, A. (2014). Development of a Framework to Enhance Information Provisioning Support for Site-based Construction Workers in The Kingdom of Saudi Arabia. In *Proceedings of the Global Conference on Engineering and Technology Management "Gaining Competitive Edge through Engineering and Technology Management" (GCETM): 23–26 June 2014,* (pp.160-166). Istanbul, Turkey.
2. Balgheeth, Y., Alaboud, N., & Zeeshan, A. (2014). Enhancing Health & Safety Management in Construction Sites by Using Mobile Computing in Saudi Arabia. In *Proceedings of the Global Conference on Engineering and Technology Management "Gaining Competitive Edge through Engineering and Technology Management" (GCETM): 23–26 June 2014,* (pp.301-307). Istanbul, Turkey.

Book Chapter

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Workshop Paper

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Abstract

Construction projects are information intensive. A typical project generates tens of thousands of documents in the form of drawings, change orders, requests for information, specifications, etc. To ensure effective construction communication and coordination, it is essential to manage this information flow efficiently. Recent improvements to IT technologies have enabled construction companies to overcome some of the communication and co-ordination challenges they face. For example, the increased acceptance and widespread use of mobile computing and wireless technologies creates an opportunity to improve productivity and lower costs, by improving information flows to allow greater collaboration and information sharing between on-site personnel. The Construction industry in Saudi Arabia is experiencing rapid growth, with many huge infrastructure projects that are government financed. These projects are subject to delays and poor productivity and faces the challenge of remaining competitive or risk being overtaken by multinational companies who are reaping the benefits of up to date technologies. However, the construction industry in Saudi Arabia has peculiar characteristics, such as its multi-cultural workforce, high level of fragmentation, low level of employee education, extreme natural environment, and the transient nature of the construction workforce. These factors complicate the implementation of new technologies and other improvements to construction processes and practices. The literature is in broad agreement that digital communication technologies will have a positive impact on reducing costs and raising productivity; however, there is less understanding of why these technologies have not been more widely adopted. This study examined the general context and condition of mobile computing, and then explored the circumstances peculiar to Saudi construction projects. It then analysed the characteristic patterns, relationships, work processes and communication tools at Saudi construction sites, and discussed this information in reference to the literature to enable the researcher to develop and validate an implementation framework strategy for mobile computing by using Interpretive Structural Modelling (ISM) methodology. This framework strategy would enable any Saudi construction company to implement a mobile computing solution that meets its needs.

Chapter 1: Introduction

1.1. Chapter Overview

This chapter presents the research and sets out background information, focusing on the need to improve communication at construction sites in the Saudi context. This chapter begins by presenting an overview of the Saudi construction industry. Key challenges affecting the management of construction projects within Saudi Arabian public sector projects are also analysed. Then follows a description of the nature of the research problem, illustrating key research aims and objectives. The scope and limitations of the research are also presented, alongside a discussion of the expected contributions of the study to knowledge. The research methodology is then outlined and finally, the structure of the thesis is presented.

1.2. Research Background

In recent years, construction projects have been subject to new demands, because of the increasing complexity of design, health and safety requirements, and increasingly stringent regulations. Construction clients, including Governments (i.e. the construction industry's major client), are becoming increasingly demanding, asking for better value for money, setting clearer expectations, and emphasising sustainability goals during building's construction and operations phases (e.g. UKCO Government Construction Strategy, 2011). Moreover, the construction industry has encountered increasing pressure to improve productivity and address the communication and coordination challenges that frequently result in projects failing to meet their golden triangle objectives (i.e. cost, time, and quality). Dainty et al. (2006) indicated that poor communication practices are a serious delimiting issue for the industry. This is currently aiming to develop a capable workforce to "deliver transformational change in the next decade" (Construction 2025, 2013). In addition, the Construction 2025 Report sets out ambitious targets for the construction industry, including reducing project procurement periods by half and costs by one third by 2025.

To address some of these issues, Information and Communication Technologies (ICT) has been extensively been applied within the industry to address communication and coordination challenges and enhance productivity, performance and quality in the design and delivery of construction projects. In comparison with other industries, ICT adoption in the construction sector is generally perceived as limited; however, predictions for future adoption are optimistic (Brandon et al., 2005). The vast majority of construction work takes place on construction sites, which are typically hazardous and dynamic environments. In fact, ILO (2005) attributes 25-40% of fatalities in the occupational setting worldwide to the construction industry. Furthermore, Anumba and Wang (2012) indicate that the fragmented nature of construction site conditions inhibits the free flow of information, to and from construction operatives. Despite the increased development of ICT in recent years, the benefits of such technology have typically been limited to office-based staff.

Construction projects are information intensive; for example, a typical project generates tens of thousands of documents in the form of drawings, change orders, requests for information, etc. Printed drawings remain the most prevalent method of communication across construction sites. Isikadag and Underwood (2010) maintain that the inherently fragmented nature of the construction industry, its heavy dependence on document-centric workflows and issues of software interoperability, impact negatively on project communication, ultimately compromising project outcomes. Kimoto et al. (2005) highlighted problems resulting from fragmented processes, such as human error, delays and the inflated costs associated with translating paper-based data to digital and vice-versa, as information flows between the site and the office. In recent years, a wide range of publications have highlighted the communication challenges that inhibit construction project delivery. Kelsey et al. (2001) explains that information provisioning to sub-contractors is often either deficient in detail or laden with excess and irrelevant information. On this basis, Isikadag and Underwood (2010) emphasised that a system of collaborative working would be of benefit, by providing capacity for inter-participant co-ordination, whilst allowing individual team members to work autonomously.

Many construction projects have failed to meet cost, time and quality targets, having been disadvantaged by poor communication and coordination problems between site-based and office-based staff. The subsequent literature review, demonstrates that a need for innovative tools and processes to address construction communication and coordination challenges has long been highlighted (e.g. Latham 1994; Egan 1998; Government Construction Strategy, 2013). Therefore, for effective communication and coordination, it is important to manage construction information flow proficiently. Recent developments in technologies have facilitated improvements to construction methods and processes, enabling firms to overcome various communication and co-ordination challenges. In recent years, public owners, contractors, consultants and designers have shown a growing interest in the utility of both Information Systems (IS) and Building Information Modelling (BIM), to assist both organisation and collaboration. Alongside these remarkable developments, construction industry growth has created a direct interest in their use to enhance construction production. In addition to IS and BIM, there have been parallel developments in the areas of cloud computing, wireless networking and mobile technologies. The increased computational power available on mobile devices, and improved connectivity solutions, mean it is possible to extend the benefits of various collaboration technologies such as BIM and IS to the point of work.

Chen and Kamara (2011) highlight the potential of mobile computing to expand the scope of information systems from site office to work site, to ensure real-time data flow to and from construction work sites. Mobile devices present themselves as “the most prominent tools to improve information accessibility, enhance management effectiveness and increase operational efficiency” (Son et al., 2012). Given that the vast majority of construction work takes place on-site, “mobile computing technologies provide engineers with unprecedented opportunities to innovate the existing processes of construction projects” (Kim et al., 2011). Nof (2009) highlights other benefits, including safety in the workplace and improvements to productivity rates. These improvements are critical, since traditionally, productivity in the construction industry has performed badly relative to other industries. Ever-increasing costs, a poor health and safety record, high accident rates, delays in completion, and the poor quality of completed work, have been the subject of several studies on construction productivity. Therefore, there is good scope for mobile computing to play a pivotal role in benefitting the management of construction project information to improve existing processes (Anumba & Wang, 2012; Kim et al., 2013; Son et al., 2012).

1.3. Background of Saudi Construction Industry

This research focuses on the construction industry in the Kingdom of Saudi Arabia (KSA), addressing some of the key communication and coordination dilemmas faced by the industry by proposing the use of mobile computing tools and processes. The KSA's development plans and large-scale investment in infrastructure, reflect its strong economy. Investment in the country has led to an extensive network of trains, roads, bridges, dams, airports, ports, facilities for electricity, and desalination, with more projects underway. The KSA construction industry has become the "largest construction sector in the Middle East and remains a 'construction safe haven' amid both wider political and financial turmoil" (Deloitte & Touche, 2013). Figure 1-1 illustrates the development of the construction industry, which is largely sourced and driven by the government.

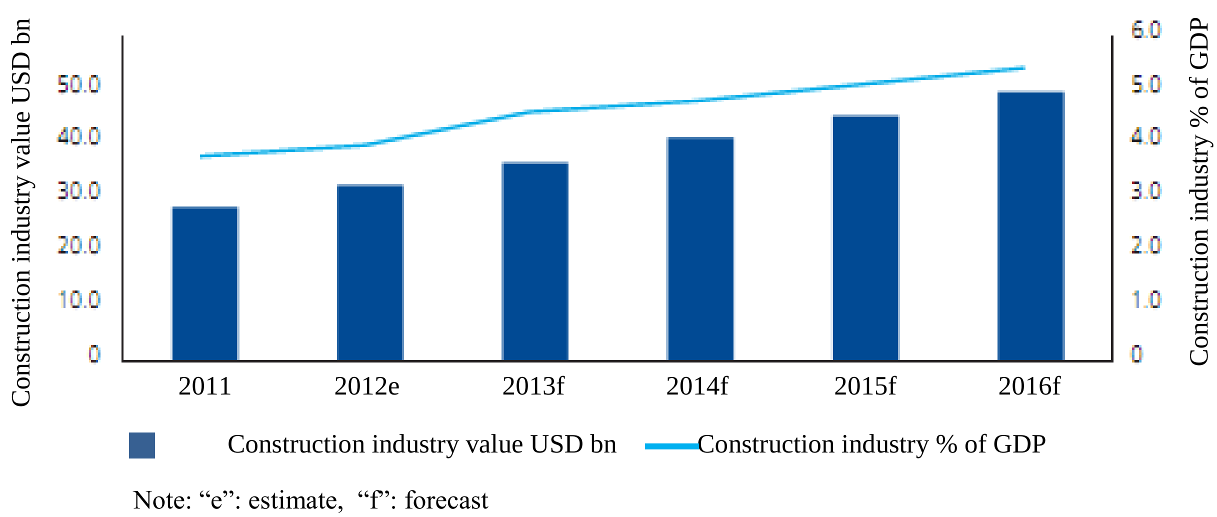


Figure 1-1: Estimated construction growth in Saudi Arabia (Deloitte & Touche, 2013).

However, with this growth, the industry is confronting a variety of challenges related to systemic shortcomings associated with cost, time management, and quality targets. Generally, as Deloitte and Touche (2013) indicated that in 2012, the total value of delayed projects was USD 146 bn, as estimated by Saudi Arabian contractors. The industry suffers from delays for various reasons, including "poor project management, low labour productivity, communication and coordination problems" (Alsuliman et al., 2012; Albogamy et al., 2012). Sidawi (2012) conducted a survey of construction companies in the KSA, which revealed that 89% of respondents use traditional communication systems and tools such as fax machines, mobile phones (voice and texts), site visits, weekly/monthly reports, and face-to-face meetings to manage projects. Furthermore, it found that 93% of survey respondents use no forms of mobile computing, aside from mobile phones for voice communication (Sidawi, 2012, p.10).

A wide body of literature is focusing on productivity improvements at construction sites. However, the majority of this literature pertains to western developed countries. There is considerable variation between construction sites in KSA and those in the West. Specifically, the KSA construction industry is characterised by multi-cultural, multi-language, low and semi-skilled labour, and very low adoption of technology, coupled with a heavily subsidised AEC sector, which fuels various process inefficiencies (Alsehaimi, 2011). All of these factors combine to complicate the implementation of new and unfamiliar technologies and processes.

This research will build an understanding of the information requirements of site-based construction workers, particularly site supervisors and site engineers. It will draw on case studies and surveys to describe the limitations of traditional embedded work processes associated with the random and undirected use of voice calls and paper based information. It will also describe how the adoption of mobile computing in a structured and formal way would modify and streamline work practices, tilting the management axis from the vertical to the horizontal, thereby increasing collaboration and reducing autocratic behaviours. The goal is to investigate the viability of extending mobile computing, and to construct a framework for the successful implementation of technological solutions to serve the continual need for information within Saudi construction practice.

The Saudi construction industry must be aware of the market and its likely transformation over the next ten years. In Western countries, governments have intervened to assist the delivery of declared policy aims, such as the incorporation of new digital technologies into the business environment, helping to establish certainty in the market by ameliorating the risk associated with investing in innovative technology. An example is how BIM is becoming increasingly relevant in other countries (Hore and Thomas 2011). In 2010, 50% of the industry in the US and 36% in the UK, Germany and France were reportedly using BIM (McGraw Hill Construction, 2010, quoted in Hore and Thomas 2011, p2). Similar trends are evident in Canada, Australia, Asia, and Scandinavia. In these settings, designers and contractors collaborate to make efficient use of these processes. At present, the threat from the perspective of the Saudi construction industry is that it will fall behind other countries adopting technologies and the updated working procedures associated with them, with the result that it will be unable to compete in terms of efficiency. This research will look into some of these challenges and investigate possible solutions.

1.4. Process Innovation Using Mobile Computing

Around the start of the millennium, all new mobile phone users were busy uploading ringtones. In the passing of little more than a decade later, smart-phone users now negotiate the uploading of functionality enhancing self-contained software programs, otherwise known as APPs. Tens of billions of APPs are available (Shelton, 2013), and 102 billion apps were downloaded in 2013 (Guardian, 2013). This mushrooming of innovative software, and the possibilities and opportunities offered by mobile application development, in conjunction with improvements to hardware devices, promise unlimited potential for commercial applications. Such powerful devices, coupled with increasingly sophisticated software, offer genuine opportunities for enhanced communication.

The ubiquity, multi-functionality, and connectivity associated with digital mobility, offers access to a new and potentially powerful networked commercial environment. The smart-phone, initially seen as a phone with added-on computing capability is now akin to a mini-computer, which incidentally, can also make phone calls. The new generation of smart-phones prioritises continuity and spontaneity across different contexts of use, while offering innovative ways of communicating. The influence and impact of this capacity to be informed and connected has migrated beyond the personal lives of smart phone users into everyday commercial transactions, where industries and professions are feeling it. Historically, the way people work and function has always altered as new tools become available. This brief introduction highlights the changes, which have taken place over a relatively short period, in terms of how people communicate within the work environment. Not only are transactions being digitised as data is generated and analysed in new ways, but previously unconnected objects, people, and activities are being connected in the new context of mobility. Adapting to ubiquitous digital connectivity is now essential to promote competitiveness in most sectors of the world's developed economies (Iansiti and Lakhani 2014).

The combined effects of social technologies, the mobile internet, cloud computing and the standardisation of commercial software is creating new business opportunities, side-lining unprepared companies, and transforming industries (Shelton 2013). The construction and other industries must be agile in their timing, making bold and decisive decisions to realise the commercial potential of pervasive digital technology. Bloomberg (2013) described agility, in a commercial context, as the "ability to respond quickly and efficiently to change in the digital business environment and to leverage those changes for competitive advantage" (Bloomberg, 2013, p6). By updating and integrating existing assets within a unified digital umbrella, interested companies can increase their value, defend against late entrants to the digital market, and increase their productivity (Iansiti and Lakhani 2014). Organisations must adapt and evolve or be left behind. The vision of ubiquitous mobile digital technology, affording almost instantaneous access to information has become a reality.

The pervasive and universal ownership of Smartphones has acquainted construction personnel at all levels with the skills and capacity to manage and retrieve information via digital means. This familiarity offers huge potential to improve the construction project delivery process. In addition to allowing the capture and delivery of real time data from site operations, pervasive mobile digital technology offers a potential training medium, improves collaboration, benefits the safety and security of the workforce, offers context aware information and service delivery, improving construction site management, design collaboration, and up to the minute visualisation, sensing and tracking (Anumba and Wang, 2012). A key to obtain maximum benefits is effective integration of emerging technologies with existing process and practices.

1.5. Research Rationale

Currently there is paucity of published literature on how construction processes and practices within KSA could be enhanced using mobile computing. Anecdotal evidence suggests increasing use of mobile devices on Saudi construction sites. However, without adequate understanding of information requirements and study of existing processes, implementation is usually ad-hoc, resulting in sub-optimal benefits. An exploratory study of mobile computing trends in Saudi Arabia reveals that mobile phone subscriptions reached 53 million in 2013 (a population penetration rate of 181.6%) and that users readily upload Apps facilitating "seamless and instant access to data anytime/anywhere" (Alotaibi and Mohammad Ibn, 2015). However, no study has investigated the commercial implications of this rising availability of information, and to date, the use of mobile computing in the context of Saudi construction is uncharted research territory. General research pertaining to this sector published around and since 2010, has witnessed a shift from discussions concerning potential, to practical considerations of how and in what contexts to apply technology to improve onsite communication processes. The general tone of contemporary research promotes a direction of change in the 21st century that will involve technological innovation bringing about a wave of automation in labour intensive industries.

The Saudi government acknowledges that it currently faces two “great challenges”; firstly, “the rapid growth in population”, and secondly, to “equip its young people with the skills needed to enable them to find gainful jobs in an increasingly integrated and competitive global economy” that relies on “science, information and technology” (KSA -Human Development Report, 2003, p67). However, in recent years, construction industry, despite being major employer, has attracted workforce from overseas and failed to attract local well-educated Saudi workforce. There is need to modernise the Architecture and Construction industry so that it could attract local well-educated Saudi workforce.

An element of the shift towards global standardisation is the ‘capture’ and digitisation of knowledge. It is generally recognised that effective information management, as enabled by mobile devices, BIM and other ICTs, could offer numerous potential benefits to enhance site based construction processes. Firstly, simply capturing up to date, accurate information means the work that follows will be of value with waste reduced; information is accurate, up to date and accessible. Author’s experience of working in KSA industry demonstrates use of word of mouth as still a key method of information package. There is some usage of a variety of software packages and ICT tools to enhance construction processes, however, approaches used are ad hoc, leading to core issues of lack of productivity and efficiency within KSA construction sector not being addressed.

In order merely to sustain current low productivity levels, and to overcome some of the intrinsic weaknesses of the Saudi construction industry in the medium term, new technologies and processes must be implemented. This research will describe how adopting a structured and more formal use of mobile computing will modify and streamline work practices, potentially increasing onsite collaboration, and reducing the more traditional management styles. There is need to address both socio-technical approaches. There is dire need to increase capacity of Saudi work force.

1.6. Research Aim, Objectives & Outline Method

This research aims to develop a strategy for the successful implementation of mobile computing to enhance information provisioning support for the contractors' site-based workers on construction projects in the Kingdom of Saudi Arabia.

Key research objectives include:

1. To develop an understanding of the literature in the area of the mobile computing applications for site-based construction workers;
2. To identify the benefits and challenges in providing timely and relevant information to site-based construction workers engaged in public sector construction projects in KSA;
3. To determine key information requirements for mobile construction workers in KSA.
4. To explore existing technology usage among the Saudi site-based construction workforce;
5. To develop a strategy for the successful implementation of the provision of pervasive mobile digital technology to support the information needs of site-based construction workers; and
6. To validate the developed implementation strategy with industry practitioners.

Table 1-1Summary of the key research methods, research questions and research methods adopted

P Primary Method / S Supporting Methods		Research Methods			
Objectives	**Research Questions**	**Literature review**	**Survey**	**Case studies**	**Focus Group**
To develop an understanding of the literature in the area of mobile computing applications for site-based construction workers	What is the global best practice in use of mobile computing for construction work?	P			
To identify the benefits and challenges in providing timely and relevant information to site-based construction workers engaged in public sector construction projects within KSA	What are the key benefits and challenges of using mobile computing in construction as perceived by KSA construction industry?	P	P	P	
To determine key information requirements for site based construction workers KSA	What are the key information requirements of the site based workers?	S	P	P	
To explore existing technology usage in Saudi Arabia for site based construction workforce	What are the existing communication technologies that are used by the site based workers in KSA context?	S	P	P	
To develop a strategy for the successful implementation of the provision of pervasive mobile digital technology to support the information needs of site-based construction workers;	How mobile IT can be deployed on KSA sites using available technologies?	S	P	P	P
To validate the developed implementation strategy with industry practitioners	How is the developed strategy aligned to the needs of KSA industry?				P

1.7. Limitations

The research focuses on the context of the KSA construction industry. There are several limitations relating to the literature available, specifically that covering world-wide construction, which describes a variety of communication tools in use, related to company size and ambition, the skills of the workforce, and attitudinal factors. However, much of the data collected by previous researchers was swiftly superseded by technological developments, making it out of date.

The literature covering the Saudi construction industry typically focuses on project delays, diagnosing the problems leading to delays at the expense of finding solutions to overcome them. There is also a limited amount of literature on the topic of construction communication. The published literature is focusing on a particular type of project, which is constructed in the remote areas in Saudi. In addition, in the research worldwide, many scholars have discussed the potentials and the benefits of using mobile computing in construction projects but few have developed IT prototypes. However, there is some very limited literature, which focuses on the actual implementation of mobile technology at construction sites. Thus, the conclusions drawn within this thesis must take the constrictions on available data and focus into account, especially when extrapolating conclusions reached in one country's construction industry to that of another.

The goal of this qualitative research is to understand the communication and information needs of site-based workers in an on-site setting. The research therefore relies on compiling an understanding of the needs of on-site managers, by listening to and interpreting interview data, to understand the meanings they associate with their experiences. In addition to interviews, the researcher observed workers onsite to deepen understanding of the communication processes of workers, within the context of their everyday lives.

However, generalising from the sample to the wider population is difficult. What is successful at one Saudi construction company might not be successful when transplanted into another. Searching for a single, universal formula, which will enable any construction company to design and implement a mobile computing system that meets its specific needs, may be beyond the scope of this research. Construction projects are complex and lengthy, and involve many different occupational (and national) groups. The on-site use of ICT in a Saudi context must take into account the complex nature of organisational change and the attitudes of the managers and workers involved. However, the results of this research can be applied to other settings, providing a flexible and adaptable strategy that can take account of, and understand the limitations of the role that technology plays in our ways of working, and how we communicate with others in the workplace.

1.8. Research Scope

This research focuses on mobile computing, Saudi construction sites, information requirements of construction site personnel, on-site information, and the interrelationships and interactions between workers, aiming to provide solutions to support them. The scope of this research will highlight and cover the following points:

1. A strategy for construction management, particularly at the contractor level.
2. The opinions of practitioners using the strategy on the contractor's team such as project manager, site supervisors, site managers, etc.
3. A sample of Saudi construction organisations, selected based upon the size and complexity of ongoing projects and deliberate targeting of contractor firms classified as top three in the category of buildings and roads (determined according to the Saudi Agency for contractor classification in the Ministry of Municipal and Rural Affairs (MACC, 2013).

1.9. Expected Contributions to Knowledge

This research will develop a strategy for the practical use of mobile technology to enhance information provisioning among the site based workers in KSA, which requires:

1. In depth understanding of the key benefits and challenges for providing timely and relevant information;
2. Prioritisation of site based worker's needs;
3. Identification of key information needs;
4. Planning a strategic guide to implement the mobile computing in Saudi Arabia construction projects;

1.10. Primary Research Areas

According to the research aim and objectives, questions, and research scope, the primary research goal is the implementation of mobile computing at Saudi construction sites to assist site-based workers. Figure (1-2) presents the research areas that overlap to meet this research goal, which must be viewed within a broader context. The information that is generated by the construction site, the information that is directed to the site, and the information exchanged between project team members must all be covered, as this represents the base that must be served by the communication tools. Communication tools is another research area that specifically relates to the tools utilised to link the site and the onsite office. The construction industry in Saudi Arabia must also be discussed, as it is the main aim of this research to understand current communication practice in this industry and explore the drivers for and barriers to utilising advanced mobile technology in order to best implement it. All these research areas, alongside an exploration of the literature regarding the use of mobile technology on a construction site need to be discussed. However, the primary research areas are discussed in detail in the following chapters.

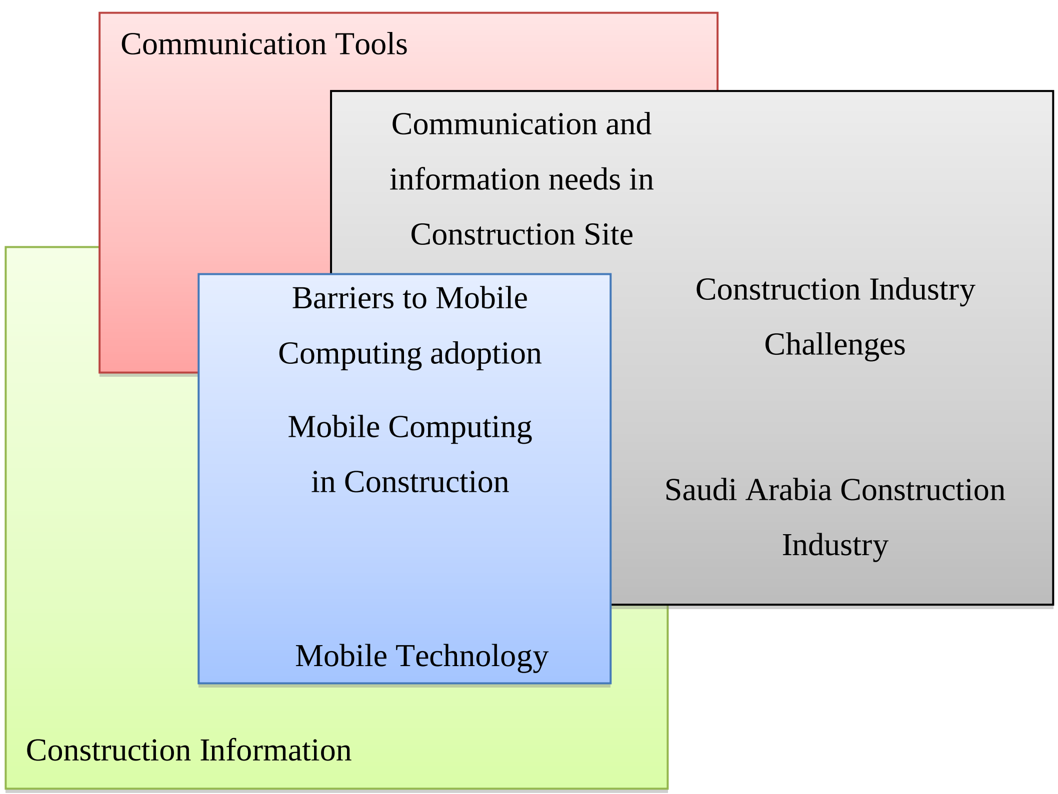


Figure 1-2: The research area

1.11. Outline of Research Methodology

The purpose of a research methodology is to collect data, answer research questions and clarify key steps informing research processes (see Table 1-1). The research methodology employed here can be first represented by the research Onion Model (Saunders et al., 2012), and then by a detailed description of different research strategies, approaches, methods, etc. The research strategy used in this research uses Case study methods (Interviews and Observations) as the primary data collection method and the Survey Questionnaire as the secondary method. Figure 1-3 presents the road map for the research stages, which contains several key stages, which will assist the researcher to obtain a comprehensive understanding of the information requirements, current practices and the surrounding issues that are essential to develop the strategy. Furthermore, a focus-group interview is conducted, using Interpretive Structural Modelling (ISM) to validate the findings with six practitioners.

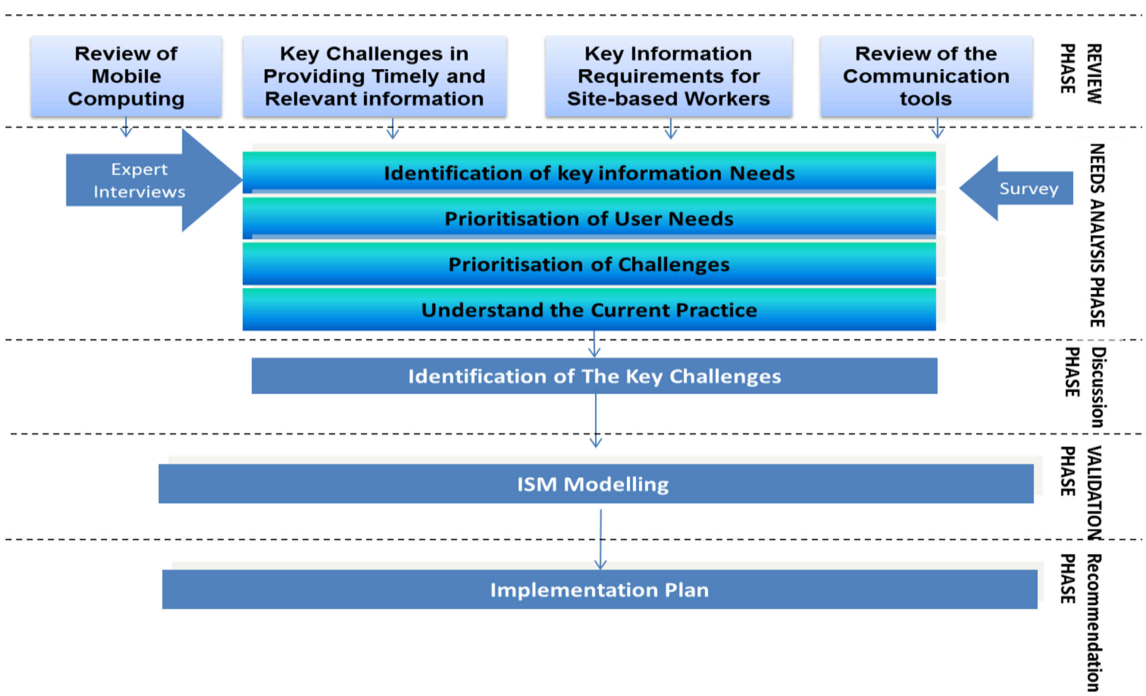


Figure 1-3: The key steps in the research process

1.12. Organisation of Thesis' Primary research areas

This section illustrates the structure of the thesis, which is organised into eight chapters described below:

Chapter 1: Introduction

This chapter presents the research background, provides an overview of the general subject area and discusses the drivers towards mobile computing use in construction. It also identifies the study's aims and objectives, justifies the research rationale, and sets the background context for Saudi construction, while stating the aims, objectives and key research questions.

Chapter 2: The Saudi Arabian Construction Industry

This section discusses the strong economic standing of Saudi Arabia, which drives its construction industry, and discusses the current states of the construction industry and the issues affecting construction projects.

Chapter 3: Mobile Computing and Construction Industry

Chapter three considers the benefits, and solutions provided by mobile computing, the motivation for automating construction tasks, and the issues related to construction information and communication. It also discusses the implementation of mobile computing in construction, and demonstrates how this research project builds on the studies which preceded it.

Chapter 4: Research Methodology

This chapter describes and explains the chosen research methodology, commencing with a description of the research design, followed by a description of the different research stages, to address the key steps in the research process. It presents and justifies the methods adopted to gather the data and its analysis methods.

Chapter 5: The Quantitative Data Results

This chapter summarises key findings from the research survey. The process of undertaking quantitative study has been described. This chapter presents key stages of the research, which helped in developing a comprehensive understanding of the information required, the communication tools used, and surrounding issues related to mobile computing usage in Saudi Construction Sites.

Chapter 6: The Qualitative Data Results

This chapter details the simple features of the data, delivering a summative assessment about the case studies.

Chapter 7: The Discussion

This chapter discusses the results of the case studies and questionnaire, summarising the study findings and discusses it with the literature based on the research objectives and questions.

Chapter 8: Framework Development and Validation

This chapter validate the results from questionnaires and case studies using Interpretive Structural Modelling (ISM) through a focus group. Looking at the challenges that affect the implementation of mobile computing for managing and controlling construction sites within the Saudi construction industry, and their level of importance while assessing the relationship between factors.

Chapter 9: Conclusions

This chapter concludes this study based on the main findings from questionnaire and case studies also from the Interpretive Structural Modelling (ISM). Recommendations are delivered in the context of Saudi Arabia in order to implement and use mobile computing.

Chapter 2: Key Challenges in On-Site Construction Management within the Saudi Construction Industry

2.1 Introduction

To reveal more information about the study context, this Chapter describes both the general and the specific setting, in order to provide an overview of Saudi Arabia by outlining background information concerning the Saudi Construction Industry. Then, the key challenges faced by the industry (Section 2.4.1, 2.4.2 and 2.4.3) are highlighted and analysed, and the underlying causes and conditions contributing to poor construction management practices within KSA discussed as driven by Objective 2. Subsequently, moving to the key point (Objective 4), the obstacles to good communication and onsite co-ordination between interested parties, i.e. consultants, owners and contractors are introduced and evaluated, and the various reasons behind it in recent literature reviewed (Section 2.4.4). Finally, a summary is drawn, which confirms the problem that this research will solve.

2.2. Overview of Saudi Arabia

Saudi Arabia is the largest country within the Arabian Peninsula, occupying an area of 2,150,000 square kilometres (830,000 square miles), making it approximately one-quarter of the size of the United States. Saudi Arabia is located at the crossroads of Europe, Asia and Africa. Saudi Arabia is currently the world's largest producer of oil, and has the world's largest oil reserves. Its oil wealth creates a financial buoyancy that cements the country's economy, thereby benefitting the construction industry. The Government is currently investing heavily in major public infrastructure projects, such as the King Abdullah Financial Centre, which will become "the first of its kind in the middle east in terms of size and planning on 1.6 million square metres and development which will have floor spaces of over 3 million square metres" (KAFC, 2013). In addition, six industrial cities' are being established across the country as economic centres, to support, extend and diversify economic growth and reduce the nation's reliance on the oil economy. Furthermore, numerous universities have been constructed, or are under construction, around the country; for example, the “King Abdullah University of Science and Technology that opened in 2009 and cost $2.7 US Billion Dollars” (Alwatan, 2009).

2.3. The Saudi Construction Sector

The Saudi Arabian Government currently plays a central role in industrial and economic development; having set economic growth priorities in ten successive development plans. The Ministry of Economy and Planning has also set out long-term economic and social development plans to achieve continuity of development in areas affecting education, health and the family, and more specifically, these development plans determine the economy’s infrastructural, industrial, commercial and agricultural needs, aiming to deliver clearly defined national objectives (MOP, 2009). However, Saudi Arabia, continues to be a developing nation, and also one that remains over-reliant on state intervention for large construction projects (Zuhur, 2011, p.161).

Development plans that support the non-oil sectors’ contributions to economic development, and the aim of developing a strong and independent private sector that does not rely on government spending and government projects, are legitimate strategies to employ to build a diversified economy (Albassam 2015). In an era of falling oil prices, the private sector’s declining share of GDP does not bode well for the state’s policy of economic diversification. In the development plan of 1985–1989, the private sector accounted for almost 49% of the GDP, whereas by 2010–2013, this had fallen, and it accounted for 35% of GDP (Mahran 2012, p.630). Mahran (2012, p.638) states that “the high dependence of the economy on oil, together with the dominant role of the public sector, leaves little room for the private sector to play a significant role in the economy”.

From a global perspective, the general decline in construction productivity is seen as a key challenge. The average annual increase in labour productivity for construction in the 1990s was 4.6%. By the period 2000-2012, the average annual increase in construction productivity had fallen to 0.3% (International Monetary Fund 2012, p.16). The construction sector’s increasing share of the employed workforce was cited as a cause of the drop in productivity growth in the 2000’s (International Monetary Fund 2012, p.17). From the Saudi perspective, the noticeable decline over time of the construction sector’s share of bank credit indicates that construction is part of the non-oil sector that does not have a competitive advantage in the Saudi economy (Albassam 2015). The decline in construction’s share of bank credit from 11.65% in 1999, to just 7.3% in 2010, is another indication that investments in construction promise an uncertain future (Mahran, 2012, p. 630). According to Samargandi et al. (2013), bank credit extended to the private sector construction sector fell from 8.2% in 2006, to 7.5% in 2010. The difference of 0.2 percentage points is immaterial, but the falling trend in construction investment is clear.

2.4. The Saudi Construction Industry’s Characteristics

The focus of this research study concerns enhancing on-site communication processes within Saudi Arabia. From this perspective, it is important to investigate key features of the Saudi Construction Industry. As explained in Chapter one, Saudi construction is heavily dependent on a transient and poorly educated multi-cultural workforce. A by-product of this dependency has been recurring delays of considerable length, impeding the completion of projects (Alsuliman et al., 2012; Albogamy et al., 2012; Alkharashi and Skitmore, 2009; Assaf and Al-Hejji, 2006). Commonly cited challenges include factors such as ineffective planning and control, poor site management, low labour productivity, communication and coordination problems, and difficulties affecting materials’ procurement. Since the beginning of the construction boom, at the start of the millennium, the Saudi construction industry has over extended itself to the point where its productivity has suffered. Deloitte and Touche (2013) estimated that in July 2012, the total value of delayed projects in which Saudi Arabian contractors are involved was USD 146 bn.

2.4.1. Delays to Public Construction Projects

Internationally, Governments are the biggest clients of the construction industry, as they sponsor huge infrastructure projects. A detailed analysis by Alkharashi el at (2009) of Saudi public sector construction projects cited five principal causes for owner-related delays. These included delays revising and approving design documents, lack of contact between construction parties and Government authorities, slow decision making by the owner, delayed progress payments, and owners' slow delivery of the site to contractors. Final payments are also apparently "notorious for not arriving", and companies must therefore, either make a provision for such costs up front, or wait several years for a court appearance (Overdahl, 2013). As evident from this analysis by Overdahl (2013), poor communication is a key contributor to project delays, and improving site communication processes would be one way of addressing some of these concerns.

In a similar study by Al-Kharashi el at (2009), five principal reasons for contractor-related delays were identified as, ineffective scheduling of projects by contractors, lack of qualified builders, poor site management and supervision, and ineffective management of project progress. Al-Kharashi et al. also isolated the causes of delays linked to consultants; as inflexibility, late review and approval of design documents, delays in completing inspections, uncertainty when approving major changes in the scope of work, and the overall inadequate experience of consultants (Al-Kharashi el at 2009). The above analysis also indicated the importance of effective site based communication for enhancing overall construction management.

Recent studies have identified various delay factors affecting the industry (Appendix B). Albogamy et al. (2012) investigated 63 different factors causing delays in Saudi public building projects. They reported that contractors were responsible for, or at least linked to many incidents of delays. The most frequent and inconvenient causes of delay were "delays in the sub-contractor's work" (Albogamy et al., 2012). Furthermore, Assaf and Al-Hejji, (2006) observed a further common cause, identified by all project stakeholders (owners, contractors and consultants), as “changed orders”. Alsuliman et al. (2012) outlined that adapting to and effecting changes to orders is a process not fully understood, nor well managed within the Saudi construction industry.

However, as this study will illustrate, access to regularly updated real-time information should alleviate this widespread cause of delay. Assaf and Al-Hejji (2006) indicated a number of other contractor related factors as contributing to project delays including; intermittent and unreliable progress payments, ineffective project planning and scheduling, poor site management and supervision and a paucity of skilled labour and contractors experiencing difficulties financing projects or parts thereof. In addition, all three parties agreed that “changes in government regulations and laws, traffic control and restrictions at job site, the effect of social and cultural factors and accidents during construction” were the least important causes of delay (Assaf and Al-Hejji, 2006).

2.4.2. Key Characteristics Of Saudi Construction Workforce

A key focus of this research effort is on enhancing on-site communications to better integrate a mobile construction workforce with back office processes. From this perspective, this section reviews key characteristics of the Saudi Construction workforce. As discussed in previous sections, construction is an important contributor to the Saudi national economy. In view of the huge investment in infrastructure construction projects, it is unsurprising that forecasts predict the largest growth in private sector employment in Saudi Arabia will take place within the building and construction sector (Ramady 2010, p.8).

One of the main factors contributing to construction industry’s role as one of the engines driving private sector growth and private sector employment has been its “easy access to low-wage low-skilled foreign labour” (International Monetary Fund 2013 p.14). In 2011, this accounted for approximately 3.5 million (45.1%) of the total private sector foreign workforce (Saudi Arabian Monetary Agency, 2013). According to the International Monetary Fund (2013, p.14), construction has not contributed to an increase in Saudi employment and is “not expected to do so” (Alsheikh, 2015, p.10).

There is limited absorption of Saudi workers into high-wage private sector jobs, and Saudis associate construction with low paid low semi-skilled work. To date, within the construction sector, few jobs have gone to Saudis (International Monetary, Fund 2013, p22), and penalties from the Government’s Saudisation policy, favouring the employment of Saudis in the private sector, has pushed up the average cost of foreign labour by 21% (Trenwith, 2013). At present the Saudi construction industry, which employs 45% of public sector workers, is characterised by multi-cultural, multi-language, low and semi-skilled labour and very low adoption of technology coupled with heavily subsidised AEC sector, fuelling various process inefficiencies (Alsehaimi, 2011). The vast majority of the disparate construction workforce within KSA have different levels of education, language usage, training, knowledge. Of the 170,000 certified engineers working in Saudi, only 30,000 are Saudis, whilst 140,000 are non-Saudis (Anaween, 2013), from a variety of different countries and cultures.

2.4.3. Communication Differences Between Multi-Cultural Workforces

In Saudi context, construction workforce is based primarily on multi cultural and multi-lingual workforce. According to Loosemore and Lee (2001 p522), most companies consider cultural diversity a “potential problem rather than a potential opportunity”. Although the communication problems across different language groups are significant for most supervisors, initiatives for tackling these difficulties are applied inconsistently from site-to-site. Ochieng and Price (2009) conclude that working relationships are most successful when the contribution of the entire project team is acknowledged. Ochieng and Price (2009, p.449) studied communications within multicultural environments on heavy construction engineering projects and found that the creation and development of effective cross-cultural trust, communication, and empathy in leadership are critical components of effective multicultural project teams. Different cultures tend to develop different rules regarding how a person in a particular position should act, and this determines the interpretation of communications with people in positions of power and influence (Loosemore and Lee, 2001, p.518).

Cultural attitudes are multifaceted and multi-layered, with the result that messages can often be misinterpreted, or interpreted differently by individuals from different cultures. Arguably, the adoption of digital technology in the workplace could have a role in reducing this misunderstanding (Loosemore and Lee, 2001, p.518). Effective communication is key to managing expectations, misunderstanding, and misgivings in multicultural project teams. For a multicultural project team to be fully integrated, all team members need to trust and understand one another (Ochieng and Price 2010, p.460). Trust is fragile and difficult to quantify, but is essential to the success of multicultural teamwork. It can be cultivated in settings where good interpersonal skills and mutual respect exists between project leaders and team members.

2.4.4. Implementation of ICT in Saudi Construction

A 2012 survey of Saudi construction companies by Sidawi showed the majority (89%) used traditional communication systems and tools, such as fax machines, mobile phones, site visits, weekly/monthly reports and face-to-face meetings. Even in 2012, it was found that aside from voice calls on mobile phones, 93% of respondents did not use mobile systems or tools to manage or record site related information. These percentages describe an almost uniformly traditional approach to communication and information sharing, suggesting that users feel most content and secure communicating verbally, either face-to-face or by phone.

Two fundamental conditions help explain this heavy reliance on ‘traditional communication methods’. The innate preference for sharing information verbally, and the implied aversion to using and maintaining written records. Cost may have deterred the formation of a community of techno-efficient users, and aside from the issue of availability, there may be a lack of motivation to substitute unfamiliar technology for tried and tested modes of social exchange implicit to verbal engagement, which have functioned well in the past.

Regardless of the reasons, Sidawi (2012) states that Saudi construction companies communication system are undoubtedly predominantly ‘pre-digital’; with the exception of the two–thirds of companies which use e-mail. If these figures are accurate, one-third of companies are not using email to communicate during the course of conducting their business. This situation would be untenable in most modern construction companies. The picture portrayed here is one of a digitally averse business community, which values face-to-face vocal exchange, and written exchange, as a validation of trust. Moreover, writing is a less expressive and more time-consuming medium than the ease, expressiveness and immediacy speech.

Within KSA context, a key barrier to adoption of electronic information management is a slow moving organisational structure and conservative business practices (Sidawi, 2012; p110). Also, Sidawi highlighted technical issues such as cost, maintenance, technical and management support; rigid and inflexible organisational structures resistant to change, and the level of staff IT skills. In a similar study, Sidawi and Al-Sudairi (2014) indicated that the traditional management practices are realised as a barrier to the full utilisation of Advanced Computer based Management Systems (ACMS).

2.5. Summary

This literature review presented in this chapter has highlighted complexities involved within construction communications (Section 2.4.2, 2.4.3 and 2.4.4). Literature review also indicated potential of mobile communication technologies and processes in encouraging collaboration and fostering direct communication processes among contractor project teams as discussed in Section 2.4.1. Thus, it will attempt to elaborate on a potential catalyst for changes to communication processes, i.e. mobile computing, to establish the evolution of a formalised, structured and transparent work record as discussed in Section 2.4.4, and as will be highlighted in Section 3.5.3. However, further to Section 1.5, a review of the literature on Saudi project management practices that regarding Objectives 3 and 4 reveals a reliance on outdated and inaccurate data, and excessive and superfluous information, resulting from an information overload that leads to ineffective communication (Figure 2-1).

The outcome of which can be poorly synchronised communication between a construction site and related site offices as outcome for Objective 4, which is covered in Section 2.4.4, leading to delayed decision making, building mistrust between contractor headquarters, the client, supply chains, and other stakeholders. Another contributing factor to poor construction management practices, which is an outcome related to Objective 2, covered in Sections 2.4.1 and 2.4.2, and includes poor site management practices and ineffective planning and control by contractors. To understand the scale of the change proposed, it is important to emphasise here that the Saudi construction sector currently relies heavily upon a document centric communication model and traditional management methods, supplemented by basic communication tools such as voice calls, which relates to Objectives 3 and 4.

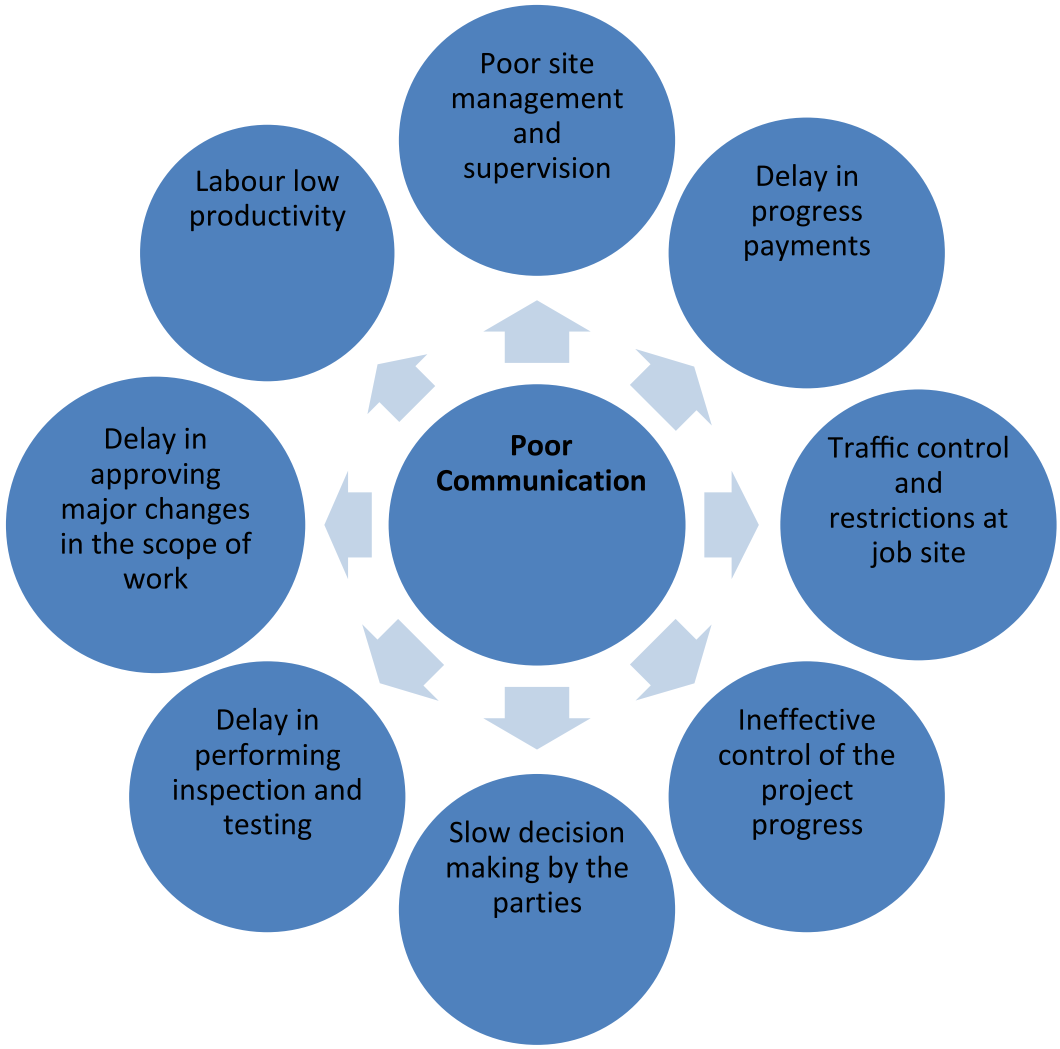


Figure 2 1: Summary of the key problems afflicting the Saudi Construction Industry (adapted from Assaf and Al-Hejji, 2006 and Al-Kharashi al et., 2009; Albogamy et al., 2012; Sidawi, 2012)

Chapter 3: State of the art review of Use of Mobile Computing within the Construction Industry

3.1. Introduction

Chapter 2 revealed the research problem, which is that Saudi construction projects currently rely heavily upon a document centric communication model and traditional management methods, supplemented by basic communication tools, such as voice calls and paper-based documents. This makes information outdated, inaccurate, excessive, and superfluous, and causes an overload that leads to ineffective communication. The nomadic and fragmented nature of site-to-site work requires that strategies need to be put in place to enable construction workers be able to communicate effectively and access up-to-date project information while remaining mobile.

Further to Section 1.4, mobile computing technologies have the capacity to ensure the right information is delivered to the right person at the right time as presented in Section 3.3. This chapter, driven by Objectives 1 and 2, reviews how existing literature has responded to the revolution in mobile computing and highlights, as required by Objectives 3 and 4, the role of information and communication technologies in the construction industry in Section 3.4. Furthermore, it contextualises the communication tools currently used in construction projects, and describes the type of information required by site-based workers. It also briefly describes and evaluates a selection of the systems and research projects proposed in the literature, emphasising the fact which an outcome for Objective 1 that mobile computing is at an exploratory stage, and currently consensus regarding what combinations of hardware and software suit particular conditions in Section 3.5. The chapter concludes with the outcome of Objective 2, a description of the benefits and challenges that affect technology adoption in Sections 3.5.3 and 3.5.4, as an extension to Sections 2.4.2 and 2.4.3.

3.2. Background to Mobile Computing

Davies and Harty (2013, p 16) provide a contemporary and balanced assessment of the application of digital technology in the construction industry, stating that, although its most vocal adherents have been disappointed by its progress, mobile computing is growing. They argue that, notwithstanding the benefits it delivers, IT adoption is still generally thought to be limited, and predictions regarding its future adoption have proven optimistic (Davies & Harty, 2013, p.16). Nevertheless, Chen and Kamara (2007) recognise that, "Advances in affordable mobile devices, increases in wireless network transfer speeds and improvements in mobile application performance, give mobile computing technology a powerful potential to enhance on-site construction information management" (2007).

Son et al. (2012) argue that by using the latest smartphones to capture and transmit information, mobile computing will help eliminate the errors and delays usually associated with manual approaches. Setting aside the considerable challenge of keeping up to date with, "Advances in affordable mobile devices" (Son et al., 2012), any generalised assessment of the viability of implementing mobile computing, must address the difficulty of accommodating the different needs of separate organisations within countries. More importantly, generalisations in the literature must account for differences between countries, which could influence the success of IT implementation.

A good example is the contrast between Saudi Arabia and Scandinavia, countries that share relatively extreme but different physical site conditions, demanding different choices of hardware suitable for use in conditions of either extreme heat or extreme cold. However, differences between countries go beyond climate and topography. Scandinavian countries, in comparison with other regions, have a higher uptake of digital media (Carson & Springer, 2012: 183). Their well-developed and extensive digital infrastructures arguably lend themselves to easier implementation of mobile computing. By embedding the use of technology across their educational curriculum, Scandinavian countries have developed well-equipped technological infrastructures and consolidated repositories of IT expertise (Arnorsson, 2012). By contrast, companies in Saudi Arabia have difficulty filling IT and skilled labour vacancies (Competitiveness Review, 2008, p.50). These small but important differences between countries help inform conclusive, across the board judgements regarding the viability of mobile computing hosting in changing circumstances and specific conditions. What may work in Scandinavia might not in Saudi Arabia; each context must be assessed on its merits and reference to its own background circumstances.

Due to these wide variations in the spread and the acceptance of IT culture across different countries, and the changing technology that supports its implementation, the literature has generally restricted comments on universal application to comments on its possibilities and potential. For instance, “Extending communication technology to onsite activities has the potential to change how the construction industry operates” (Anumba & Wang, 2012), or, “The emergence of new Information Technology, such as mobile computing and mobile sensors, has great potential to enhance information management on construction sites” (Chen & Kamara, 2008b, p.2).

There is exceptional diversity and inconsistency in the construction world, and change in IT technology is too rapid, for context specific assessments to have universal application. The variety of IT solutions available, the constantly changing technology, and the different needs of separate organisations and countries, are all factors that incline the literature towards generalisations about mobile computing, and these generalisations must be qualified to satisfy specific conditions. Chen and Kamara (2007, p.8) specify four elements that interact to influence how on-site mobile computing manages information; they are: the features of mobile computing, the attitudes and experience of construction personnel, the type of construction information and the mode by which it is shared, and the conditions of the construction site. This research will examine the details associated with these four elements.

Complexity, rapidly changing technology and a variety of contextual backgrounds influences attitudinal resistance, are some of the aspects that the literature relies upon when describing mobile computing. However, as will be shown in this paper, generalisations in the literature are themselves particularly vulnerable to technological advances and therefore, broad based assessments, particularly those made before 2010, are redundant, as new devices and platforms have emerged. Chen and Kamara implicitly acknowledge literature's limitations when they state that most research focuses either, "on a detailed aspect" or a, "single facet of mobile computing" (2011, p.777).

The literature published in the last five years has been more confident in its assessments of the feasibility of onsite mobile computing because the now almost universal ownership of smartphones means that at all levels, construction sector workers have become acquainted with the managing and retrieval of information via digital means (Pierce et al., 2011). By 2013, Kim et al. (2013) indicated that the advent of smartphones, in tandem with mobile computing technology, was providing construction personnel with "unprecedented opportunities" to improve traditional management processes on-site. This familiarity with constantly improving and more user-friendly software shifted the discussion from consideration of the potential for improving onsite communication, toward how this can be achieved. Kim et al. are confident that the mobile computing potential of smartphone technology can be expected to lead to a, "Paradigm shift of the conventional construction management practices" (2013, p.422). In the course of this change of emphasis, technological change and the wisdom of hindsight has exposed as premature some of the assessments made in extant literature.

Specifically, hindsight has revealed some observations regarding the role of IT in construction to have lost relevance, and others to be mistaken. For instance, Saidi et al.'s (2002) conclusions are no longer applicable because of advances in hardware development; their experimental research concluded that technical barriers to the use of mobile computing in construction were insurmountable. However, the cited limitations of, “Screen size, screen visibility, processing capability, and input methods” have largely been overcome. What the present research cannot do is predict the improvements in hardware that will emerge in coming years; however, it can anticipate that it is very likely that there will be further improvements. Saidi et al. (2002) also identified limitations inherent in the characteristics of the construction industry; these intrinsic barriers are less subject to accelerated change and have been widely cited: the physical jobsite conditions associated with extreme temperatures, humidity, dust, the dislocation and fragmentation associated with the project-based nature of the construction industry, its low tolerance to risk, its organisational culture, how its internalised beliefs, attitudes and behaviours accommodate or resist change, and the generally conservative culture within construction firms.

The passage of time and advances in mobile hardware and software since the 2006 publication of ‘Communication in Construction: Theory and Practice’ (Dainty, Moore & Murray, 2006) have exposed the pre-digital mindset, which informed the assumptions underlying their conclusions. Research in general has largely concerned itself with design work in the office environment (Davies & Harty, 2013, p.16). Up to approximately 2010, Dainty et al. (2006) and the literature in general, focused on IT’s potential and the industry’s resistance to it, rather than acceptance of it. Attitudinal changes brought about by mobile device ownership have largely submerged these notions of ‘resistance’ and ‘potential’.

Dainty et al.’s (2006) citation of a 1997 argument in support of industry resistance to IT illuminates the rapidity of technological change. This reference stated, “For several years, many within the industry have believed that multimedia communications are set to revolutionise construction, with virtual reality used at scheme design, site meetings conducted through an intranet, and drawings transferred back and forth via email” (Bunn, 1997, cited in: Dainty et al., 2006: 193). This quotation is highlighted, because it shows the provisional quality of generalised assessments made in literature. Similarly, innovations discussed today as hypothetical or ‘having potential’ may, in a few years, become commonplace and enter widespread use. On the other hand, the emergence of unforeseen new technology could mean contemporary technology becomes obsolete quickly. The intended purpose of Dainty et al.’s quotation was to explain, “The reasons as to why (ICT’s) application often fails” (Dainty et al., 2006, p.193). In fact, with the passage of time, Bunn’s (1997) statement has instead evidenced how unforeseen technological innovation can help consolidate the successful application of mobile computing, if certain other factors are in place.

In the eighteen years that have passed since Bunn (1997) expressed scepticism, all of his ‘beliefs’ about multimedia communications have become reality. More generally, literature that pre-dates 2010 could never have anticipated how the multiple functions and applications offered by today’s mobile devices would change people’s expectations. In particular, this earlier literature generally cannot explain how these technological developments have changed attitudes to mobile devices in construction. Everyday experiences of capturing, storing and re-using information has increased acceptance of the role of IT in the workplace. As technology has developed, the challenge in terms of its implementation becomes less associated with its flaws, and more to do with organisational and management resistance to its use.

3.3. The Development of the Mobile Industry

Since approximately 2010, sustained interest in smartphones has been reflected in the consistently high volumes of the same purchased each year. Smartphones have evolved into “miniature handheld computers” (Muto, 2012), including features such as GPS navigation, high-resolution colour touch screens, digital cameras, high-speed data transfer, and more. TNS ‘Mobile Life’ (2012) conducted a global study of 48,000 users from 58 countries, illustrating the use and the desired use of different features among all mobile users (Figure 3-1).

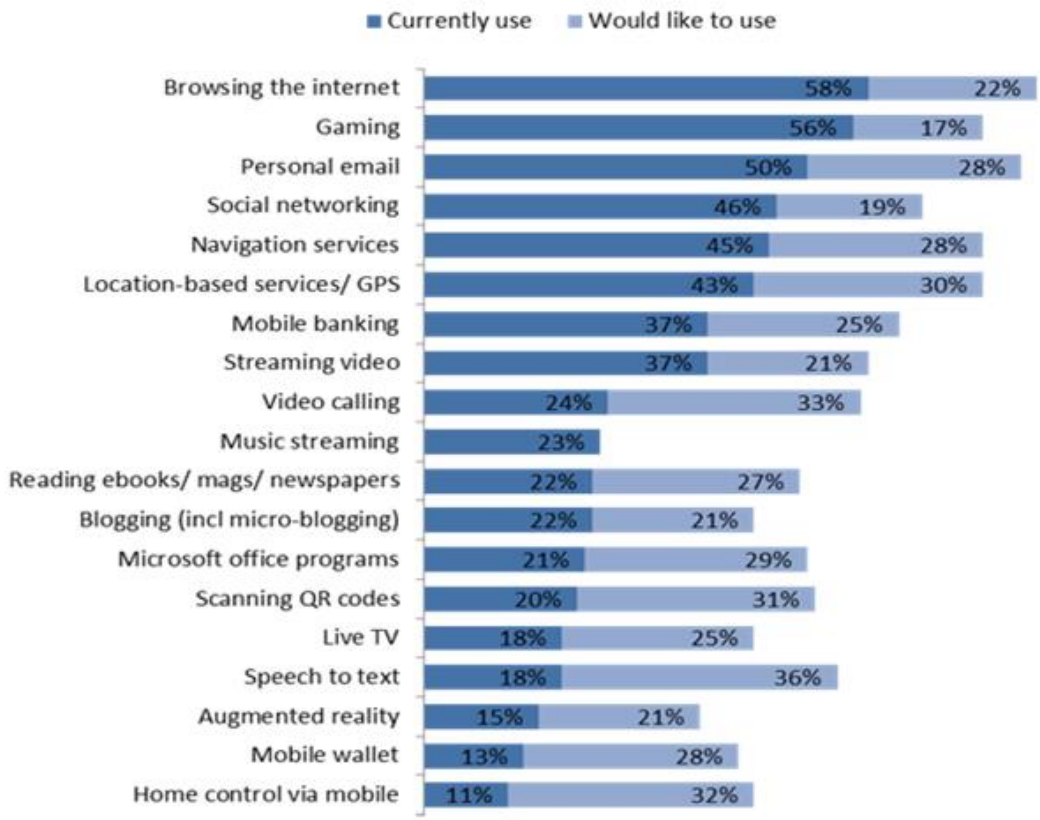
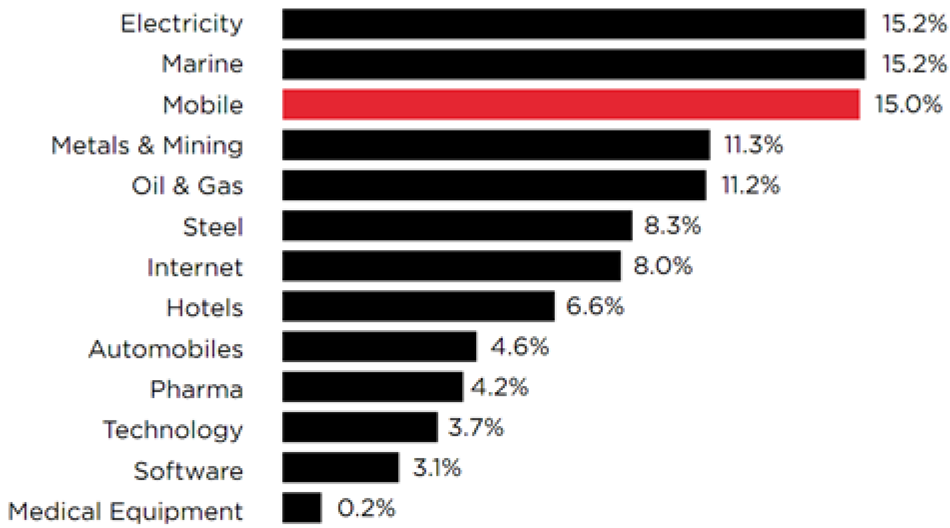


Figure 3-1: Presents the use and desired use of Smartphone features among all mobile users (TNS, 2012).

Recent years have seen a tremendous growth in mobile computing. The mobile phone industry is capital intensive; Figure 3.2 shows that it is only slightly behind the electricity and marine industries in terms of capital expenditure requirements. “In 2012 alone, the global mobile ecosystem invested US$200 billion, or 35% more than the global mining industry” (GSMAK & Kearney, 2013).



Note: Capex as a % of revenues, 2012

Figure 3-2: Capital expenditure across a selection of industries (GSMAK & Kearney, 2013)

Within construction industry, push towards uptake of mobile computing and digital construction is to a large extent driven by need for better life cycle data management. Similar drivers are found in other industries. GSMAK and Kearney (2013) stress that, "Data is the driving force of mobile growth because the volume of mobile broadband (MBB) traffic has been doubling every year, reaching 1,577 Petabytes per month in 2013 (equal to 1.6 billion Gigabytes)". Figure 3.3 shows that mobile devices have been utilised by a variety of industries to improve access to services such as banking, sanitation, electricity, education, health, and more. It has become commonplace in the US, and elsewhere, to use a smartphone to pay for coffee, car parking, or to sign off and even comment on the job completion efforts of an electrician or general mobile serviceman.

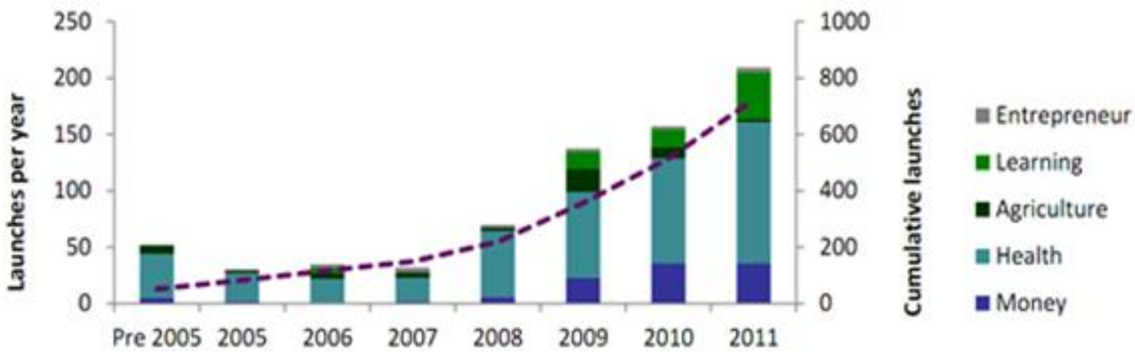


Figure 3-3: Mobile-enabled products and services in the developing world (GSMA, 2013a)

However, for other industries, there is still a general lack of understanding, despite the growth of mobile adoption. According to GSMA (2013a), this lack of understanding can be characterised according to three general areas:

- Lack of defined value chain, which is the proven value proposition for participants at each stage of the value chain, for example service providers, vendors, and mobile operators.
- A sustainable business model with the potential to become self-sufficient.
- Visibility across markets and sectors; the knowledge of participants adjacent to the sector and their ability to collaborate in areas that expand the reach or value of the service.

The drive to unify a digital approach in construction and its sectors and processes will be accelerated and better understood when the construction processes that would benefit most from the application of mobile information and communication are identified and software developed to enhance those processes (Bowden & Dorr, 2004). Increased global links will require construction organisations to build and exploit systems to share data collaboratively, with the added value of better work performance (Xue et al., 2011, p.1).

3.4. Communication and Information Needs of Site-based Construction Workers

3.4.1. Overview

As previously discussed, the construction project is characterised by a heavy workforce and generates huge amounts of information, which requires effective project management. Löfgren (2005) suggests that the poor productivity figures in the construction industry could be partly explained by the fact that the information needs and communication behaviours in the production at construction sites are not adequately met. Moreover, managing information in construction is the main success factor for performance. This section will review the communication technologies in use onsite and identify the different types of construction information exchanged on site.

3.4.2. Traditional Means of On-Site Communication

Throughout the execution of a project, a large amount of data is produced, transferred, and stored. Also, construction projects involve a large number of participants, whose aim is to exchange information to increase productivity and support decision-making. Information that is paper-based is less reliable than the almost instantaneous alternative of digitally exchanged information, as it is not automatically updated, and workers therefore have no way of knowing if amendments to the document have been updated. Nevertheless, most construction projects rely on, “Manual processes and traditional methods of communication, such as phone calls, faxes and emails to obtain such information” (Dave et al., 2010). Anumba and Wang (2012), agree that in most construction organisations, a field team’s project information access and retrieval, information editing and decision-making, are restricted to 2D paper-based technical drawings.

In 2012, Nourbakhsh et al. asked 182 construction professionals in 22 countries about the communication tools they use for on-site information management (see Figure 3.4). In the 99 received responses, cell phones accounted for 39.4% of communication tool usage, personal digital assistants were used by 23.2%, and computers were used by 15.2% of respondents for information management purposes. Other tools, such as cameras, voice recorders, walkie-talkies, and so on made up a further 22.2%. Nourbakhsh et al. conclude that there were “no significant differences” between the information requirements of respondents from different countries. Although there were variations in the volume of data shared, and the intensity of the demand for it to be shared and made available immediately, the nature of the information and the means of sharing it were similar (Nourbakhsh et al., 2012a, p.491).

It is not surprising, therefore, that similar results emerged from a 2012 survey of the information management practices of Saudi construction companies, where 70% to 89% of respondents reported that they use, “traditional communication systems such as fax machines, mobile phones, site visits, weekly/monthly reports and meetings” (Sidawi et al., 2012, p.110). They do not use mobile systems apart from mobile phones, which are used by 93% of the respondents to make voice calls. Neither Nourbakhsh et al. (2012a) nor Sidawi et al. (2012) encountered the use of web cams.

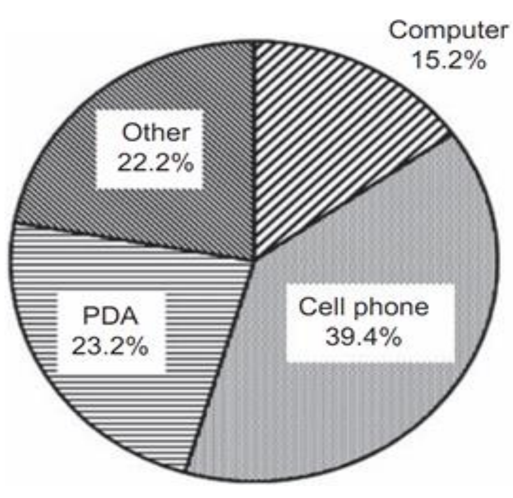


Figure 3-4 On-site information management tools (Nourbakhsh et al., 2012a).

Bowden (2005) identifies the most common paper-based tasks carried out in the construction industry to be: the completion of data collection forms at 25%, dealing with correspondence at 18%, viewing and reviewing drawings at 13%, and reading and writing specifications at 6%. Bowden et al. (2004) conclude that paper-based files limit and delay on-site communication and information exchange. According to Bowden (2005), they provide no way of filtering the excessive volumes of information, nor do they provide any means of information feedback. Even before the advent and spread of smartphones, Chen and Kamara saw the "limitation of paper-based files" as a "major constraint in on-site information communication and exchange" (2008b, p.4). Similarly, Bringardner and Dasher describe paper-based documents as "expensive, heavy, inaccessible, difficult to update and quickly outdated" (2011, p.2).

Real time computerised information facilitates two-way communication in the form of instant feedback in a way that paper-based systems do not. Bowden (2004), concludes that the lack of feedback associated with traditional asynchronous communication methods contributes to its three principal shortcomings: message distortion, gate-keeping and information over-load. Information over-load arises when information is presented in a fixed format, such as a hard copy of the printed page, which requires the reader to waste time scanning the document to search for the relevant passage, file, or sequence of pages.

The hazards of a set of paper documents become clearer when a project is large in scope and contract value. To illustrate this point, Bringardner and Dasher (2011) conducted a case study that hosted 16,099 drawings in a Project Information Cloud; the documents were synched to 31 iPads and made available to project participants, regardless of their location. Aside from avoiding the cost and inconvenience of transporting and printing drawings and other documents, digitally storing, accessing and managing project information ensures that no document is lost, and immediate access is possible without having to search through piles of paper records. 'Going paperless' meant that of the 16,099 documents, no full size sets of documents were printed.

Using mobile computing information digitally means that, for practical purposes, all relevant information can be retrieved and shared instantaneously, making work processes quicker, more accurate and therefore more cost efficient. Storing information digitally also enables access to a repository of information for current and future use. Unlike a paper storage system, there is no correlation, using digital storage methods, between the volume of information stored, the cost of storage and the ease of access and retrieval, provided the system is logically designed and easy to use. In other words, a digital system can store vast amounts of information without increasing the risk of loss or damage, or causing delays in retrieval. Efficiency of storage, speed of retrieval, and the certainty that records remain in the archive, in addition to avoiding the expense of maintaining storage space, are clear advantages.

Both Chen and Kamara (2011) and Garcia Garcia et al. (2014) draw a general link between the clogged pipeline of records stored on paper, and inefficiency and poor time management. The delays built into the methods of printing and disseminating traditional on-site communication prevent the delivery of ‘just-in-time’ information, which can create an “information deficit”, leading to the “neglect of issues that require a quick response” (Chen & Kamara, 2011, p.776). Only when the information bottleneck is cleared can efficiency be improved. Inefficiencies and poor time management are thus, “likely due in large part to reliance on manual methods, which are tedious, time-consuming, and prone to error” (Garcia Garcia et al., 2014, p.95). Project managers and engineers working on large projects are therefore disillusioned with, “The impracticality of paper documents and the processes associated with them” (Bringardner & Dasher, 2011, p.2).

The mixed-bag of verbal communication and assortment of paper print-outs still in use in less developed construction industries can lead to mistakes and delays, causing frustration among workers. Reliance on paper, voice calls and the documenter’s memory often leads to human error resulting from data loss, unreadable field notes or incomplete recollection of information. When project participants can be assured that their frequent communication means they are up to date, or that any adjustments made to building plans are complete, their confidence in the accuracy of data will assist in successful project completion (Arnorsson, 2012).

Chen (2008) highlights a recurring theme in this study, namely the strategic weakness implicit in the order-less and unplanned traditional communication and information storage system. This weakness lies principally in the absence of a centralised repository for all project data; the ramifications of which go beyond the failure of a paper information storage system to provide personnel that are new to a project with instant access to the methods and solutions previous contractors applied in difficult situations. It de-motivates all personnel from keeping and sharing a diary of project progress, which encourages a collaborative approach through sharing problems and solutions. Nourbakhsh et al. note that if such a repository existed, it could be used as a "form of communication between the project participants" and facilitate "the integration of project information" (2012a, p.475). According to Dave et al., this problem has remained unresolved because "information systems are still disintegrated" (2010).

Similarly, Bowden (2004) indicates that message distortion and information gatekeeping becomes a problem in a paper-based environment. When access to the database is under the control of a single individual in a pivotal position of influence, this privileged position can be misused to confer power on the individual rather than to disseminate information. The likely outcome of such a situation is 'message distortion', which occurs when meaning is changed by adding or deleting bits of information to protect an individual or to ensure status. 'Gatekeeping' refers to the intentional withholding of information to advantage or disadvantage individuals or groups (Bowden, 2004, p.12). This is relevant to the current research because recording and accessing computerised information presents an obvious solution to feedback distortion issues.

3.4.3. Information Needs

Information management is axiomatic to the success of construction management. Information is here defined as "data and messages transmitted between people within a communications network" (Mead, 2001, p.). In the past, scholars have expressed a variety of viewpoints regarding the value of information and have divided that information into different categories (see Table 3-1). Nourbakhsh et al. (2012a) describe how information has been categorised over a 15 to 20-year period and conclude that the demands, skills and circumstances of particular construction sites determine how information is valued and classified.

Table 3-1: Summary of the categorisation of construction information

BT (1995)	Murray and Thorpe (1996)	De La Garza and Howitt (1998)	Scott and Assadi (1999)	Cox et al. (2002)
Technical Commercial Management Control	Confirmation of verbal instructions Technical queries Site instructions Subcontractor Site instructions Dayworks Requisitions Site programmes Method statements Sketches Drawings Drawing administration Application for payment	Requests for information Materials management Equipment management Cost management Schedule and methods Site record keeping Submittals Safety records QA/QC Future trends	Finance Quality Progress	Chronological files of project correspondence and memorandums, including RFIs Change order and submittal requests Quality control and assurance records Construction field activity and progress logs Resource and inventory logs, including tracking of labour, equipment, and

	General correspondence Photographs Video			materials

To explore the relationship between project management and IT computing potential, of mobile phones in particular, and to understand how the everyday information needs in project management should adapt to this potential, it is necessary to establish the types of information exchanged on site. To understand the information requirements of relevant personnel, it must be clarified which types of documents site-based workers would most likely need to access in the field. In determining this, it is important to note that on-site information needs are intrinsically linked to the tasks being performed in the course of an operative's work.

To describe information related processes, Bowden (2005) distinguishes three information-related activities; "Data capture issues, communication issues and identification issues". The data capture issues are related to monitoring progress and checking the receipt of goods-received notes, monitoring health and safety on site, carrying out quality inspections, site investigation, maintenance inspections, maintaining site diaries, keeping timesheets, checking defect management, making field observations, tracking plant and materials, and accounting for on-site operatives and/or visitors for identification purposes. The communication issues include: the distribution and use of drawings, task allocation, correspondence, and site design problem resolution. The majority of the processes Bowden (2005) identifies as potentially benefitting from mobile IT are structured data capture processes, for example, health and safety inspections, maintenance inspections and progress monitoring, followed by communication issues, such as issues to do with the identification of plants, materials and people (Bowden, 2005, p.61).

Bowden (2005) also identifies the top ten processes perceived to offer the most potential for improvement through the use of mobile IT; it should be noted that this was written in 2005, before tablets, smartphones, and other such technology entered the market. The conclusions are prescient, but qualified by the technical limitations that existed at the time. For example, participants were very unsatisfied with using smaller screens on mobile devices for viewing and annotating drawings prior to 2005 (Bowden, 2005, p.61). Bowden (2005) concluded that an alternative way of delivering drawing-based information in the field was required, and that either devices or drawings needed to be adapted to improve their delivery by electronic means. It is safe to assume that the means of representing design drawings electronically have improved since 2005, making them easier to view and understand.

Nourbakhsh et al. (2012a) conducted a comprehensive survey (see Tables 3-2) of the types of information required for on-site construction projects, to evaluate the value placed on information and determine which kinds of data, potentially, are most in demand when designing a multi-purpose mobile application. Their aim, in a previously under-researched area, was to rate the required indicators from 44 types of information from the perspectives of the client, consultant and contractor.

Table 3-2: Information ranking using relative important index (Nourbakhsh et al., 2012a).

Mobile application information	All groups ($N = 182$) RII	Rank	Client ($N = 31$) RII	Rank	Contractor ($N = 101$) RII	Rank	Consultant ($N = 50$) RII	Rank
Change order	0.819	1	0.813	5	0.800	8	0.836	2
Accident reporting	0.816	2	0.761	10	0.815	4	0.828	7
Schedule updates	0.808	3	0.832	3	0.824	1	0.830	5
Report QC/QA problems	0.807	4	0.800	8	0.818	3	0.836	4
Site instructions	0.806	5	0.852	2	0.790	11	0.830	6
Productivity information	0.802	6	0.819	4	0.810	5	0.738	23
Delay recording	0.792	7	0.877	1	0.794	10	0.762	19
Daily report	0.789	8	0.800	7	0.798	9	0.836	3
Report inspection results	0.787	9	0.748	12	0.804	6	0.792	10
Reporting violations	0.786	10	0.774	9	0.819	2	0.796	9
Progress photo	0.781	11	0.684	23	0.802	7	0.796	8
Contract drawing	0.773	12	0.645	29	0.772	13	0.772	16
Design intent and clarification	0.772	13	0.606	36	0.762	19	0.840	1
Contract specification	0.770	14	0.671	26	0.768	14	0.780	13
Site diary	0.769	15	0.697	18	0.766	18	0.788	11
Initiate inspection	0.757	16	0.640	30	0.750	22	0.776	14
Budget	0.749	17	0.755	11	0.762	20	0.760	20
Test results	0.743	18	0.613	35	0.766	17	0.776	15
Implementation problems	0.737	19	0.626	31	0.727	29	0.718	24
Request material to site	0.733	20	0.606	38	0.768	15	0.742	21
Employee list	0.729	21	0.652	28	0.720	31	0.784	12
Exception reporting	0.727	22	0.723	15	0.717	32	0.692	31
Material list	0.724	23	0.684	22	0.758	21	0.700	27
Subcontractor information	0.724	24	0.613	34	0.766	16	0.700	29
Variation order	0.722	25	0.813	6	0.732	26	0.772	17
Work package information	0.720	26	0.542	43	0.747	23	0.716	25
Weekly report	0.720	27	0.723	17	0.733	25	0.688	34
Site meeting minutes	0.718	28	0.723	16	0.716	33	0.700	28
Material order status	0.711	29	0.600	39	0.780	12	0.766	18
Equipment list	0.709	30	0.690	20	0.725	30	0.700	26
Extension of time	0.709	31	0.690	21	0.701	36	0.740	22
Material cost accounting	0.708	32	0.748	13	0.727	28	0.682	36
Place material orders	0.699	33	0.626	32	0.729	27	0.692	32
As built records	0.697	34	0.690	19	0.737	24	0.694	30
Monthly report	0.681	35	0.671	25	0.713	34	0.674	39
Equipment cost accounting	0.678	36	0.729	14	0.703	35	0.666	40
Equipment location	0.671	37	0.619	33	0.684	38	0.690	33
Material location	0.667	38	0.671	24	0.697	37	0.682	37
Letters	0.663	39	0.587	40	0.656	40	0.680	38
Equipment inspections	0.662	40	0.658	27	0.669	39	0.682	35
Equipment servicing	0.635	41	0.606	37	0.630	41	0.648	42
Visitor's log	0.622	42	0.574	41	0.552	44	0.644	43
Employee records	0.619	43	0.548	42	0.596	42	0.648	41
Employee training	0.565	44	0.400	44	0.557	43	0.596	44

Nourbakhsh et al. (2012a, p483) list the areas in which IT could be applied to manage construction information; these include site diaries, resource management, supply chain management, resolution of site design issues, problem defect management, quality inspections, maintenance conditions, health and safety, progress records, and general monitoring. They conclude with selected information from the three perspective groups to build mobile computing application (see Figure 3-5).

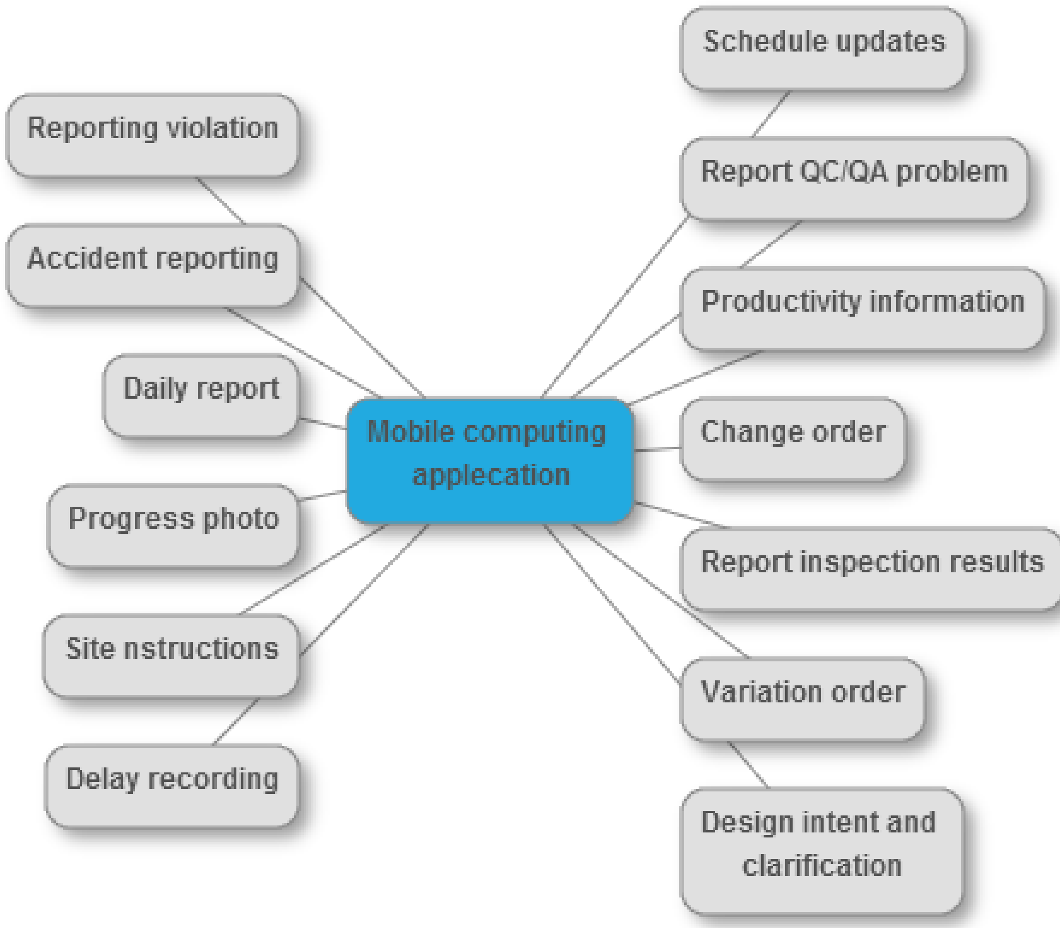


Figure 3-5: The selected on-site information to build a mobile computing applecation (Nourbakhsh et al, 2012a)

In addition, in the area of mobile computing some researchers have created or used applications in practice to access project information; for example site monitoring, task management, and real-time information sharing (Kim et al., 2013); design drawings and BIM models (Bringardner & Dasher, 2011); and Augmented Reality and BIM (Wang et al., 2012). However, as Nourbakhsh et al. (2012a) highlight, the nature of information in construction projects is that construction site has its own information classification, which differs from one site to another.

3.5. The Viability of Mobile Computing in Construction Site

In the construction phase, traditional technologies would be installed in the site offices (Chen, 2008) while few technologies are available to use on site. Only when the information bottleneck is cleared can efficiency be improved. Mobile computing extends the communication boundaries from the site offices to the work sites by connecting moving personnel and increasing their mobility. Even a limited extension of IT tools in everyday applications would open up horizontal communication channels within an organisation. The extension of software use to a few individuals, such as onsite engineers, would ease information flows, bypassing traditional information gatekeepers and reducing information overload, thereby avoiding information bottlenecks in the system. In order to realise its benefits, the intended users must buy into the usefulness of the applications. In the Saudi context, this means understanding and, where possible, bridging the gap between what is required socially within a multicultural work group, and what can be achieved technically.

This study maintains that the process improvements arising from mobile computing are not limited to improvements in communication and information sharing. By sharing knowledge and learning, mobile computing will aid the application of technology to support improvements to the work process. Anumba and Wang (2012), believe that, "Integrating mobile devices, wireless communication and mobile services" represents "the missing link in Construction Information Technology, thus providing appropriate information flow in the life-cycle of a building product" (Danijel et al. cited in: Anumba et al. 2012).

Regarding technical improvements, the capacity of mobile phones to integrate many technologies into one device reflects the variety and scope of the information tasks they can fulfill. Smartphones are currently fitted with high resolution, colour touch screens, GPS navigation, wireless communication capabilities, cameras, sensors, high-speed data transfer with 4G, GPS, and data processing, which all come together into a single hand-held device, allowing information to be easily and readily accessed by the construction team. “Smartphones and tablets, when matched to suitable software, open clear opportunities for project managers, subcontractors and craftsmen” (Garcia Garcia et al., 2014: 94). These powerful features, “Enable a new generation of on-site management processes, such as high mobility, location-based customised work orders, real time information exchange, and augmented reality (AR) based site visualisation” (Kim et al., 2013). The latest generation of smartphones support “complex multi-touch input, gesture-based interaction, enhanced connectivity, and many dedicated special purpose applications” (Pierce et al., 2011).

3.5.1. The Characteristics of Mobile System for Managing Site Information

This section discusses the aspects of the mobile computing system and its requirements. Kim et al. (2013) claim that the “potential” of “mobile computing technologies” is to improve “material tracking, safety management, defect management, and progress monitoring,” due to the mobility of smart phones, allowing any time, any place access to shared information. Lofgren (2005) points out that any mobile computing system must take account of the end user’s needs. Chen and Kamara (2011) devised an application model (see Figure 3-6) that maps six primary factors that determine how mobile computing is used on a construction site. They separate the primary factors into independent and dependent factors (Figures 3-7 and 3-8).

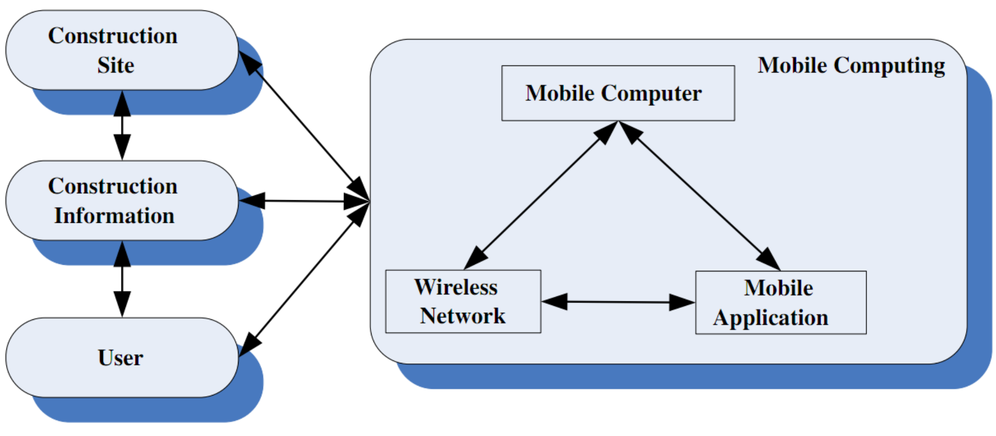


Figure 3-6: Application model for using mobile computing in information management on construction sites (Chen & Kamara, 2011).

Figure 3-6 illustrates the independent and dependent factors. The dependent elements are the mobile computer (hardware), wireless network and mobile application (software), which together constitute the infrastructure of mobile computing. The three independent factors, the user, the configuration of construction information and the location, that is, the site itself, are the fixed fundamentals, which govern how mobile computing will be used in any construction context. Chen and Kamara (2008) explore the interrelationships between construction information and mobile computing in selecting a mobile computing strategy for managing on-site construction information. This 2008 model is an attempt to represent in abstract terms the links and interrelationships between independent and dependent factors, where primary factors are divided into sub-factors that represent specific relationships.

The overall selection process includes four major stages: the clarification of the information management process, the creation of an overview of a potential framework or solution for onsite communication, the selection of a strategy to deliver mobile computing, which, once identified, will influence the choice of the most suitable mobile computing technology. Figure 3-7 shows the sub-model, which contains sub-factors of primary factors, including "construction information", "mobile computer", "mobile application", and "wireless network". As an example, the independent factor "construction information" is divided into seven sub-factors, whose collective influence will help determine what types of hardware and software are chosen, for example the information type, information format, file size, information flow, information processing, information source, and information destination. As the dependent factor, "mobile computer" contains the following sub-factors: operating system, processor speed, storage capacity, data input, data output, physical feature, battery duration, and connection method (Chen & Kamara, 2008, p.13).

The model is an abstract representation of how mobile computing can provide specific construction information to users. The digital representation of construction information enables its presentation in various formats, including graphics, imagery, text, and verbal. Chen and Kamara state that the "format of construction information has a major impact on the output method of the mobile computer" (2008). However, the mobile phone is now able to deliver all these formats. They further state that the "storage capability of the mobile device should be able to store the necessary information files;" cloud computing has now largely removed the issue of file size and file storage. Information processing activities carried out by users, such as accessing drawings, editing files, making notes, recording progress of work tasks, and taking pictures, will determine the selection of appropriate software.

Chen and Kamara's (2008) analysis of the role of the 'information flow' is symptomatic of research that pre-dates the enhanced capacities of the smartphone in conjunction with cloud software. 'Information flow' refers to, "whether information is retrieved from other construction employees to construction work sites or is transferred from construction work sites to other project information system or employees" (Chen & Kamara, 2008, p.). Although cloud computing has made elements of their conceptual framework redundant, information flow is still worthy of comment, as by choosing a single individual to transfer data from the construction work site to an office based employee, Garcia Garcia et al.'s (2014) Construction Progress Control system avoids the complexity of involving multiple participants and follows a unidirectional asynchronous information flow, limited to the collection and transfer of site data to an offsite PC. As there is only one recipient and one sender of the data, it is more properly termed an 'information retrieval tool', rather than an information sharing tool.

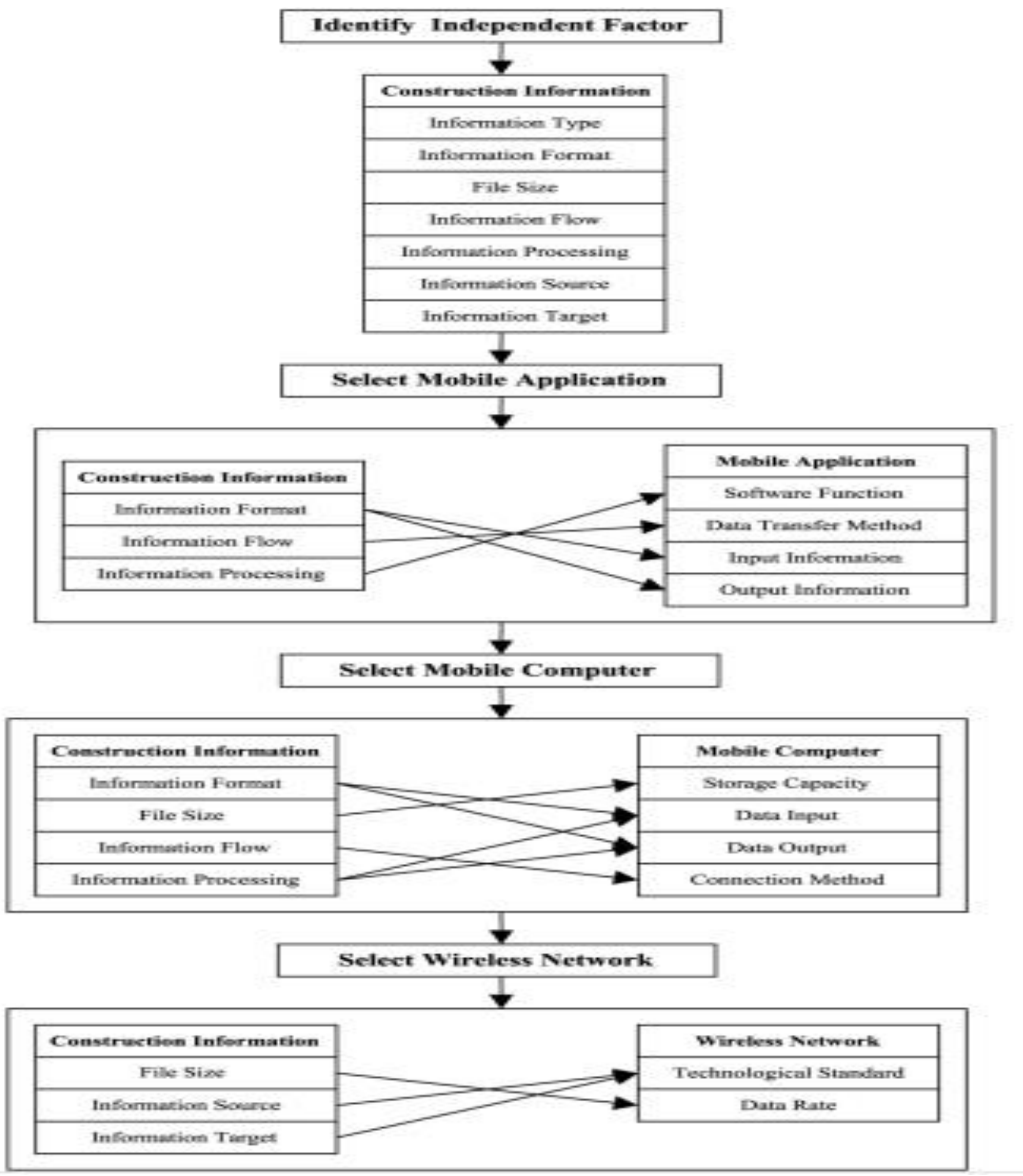


Figure 3-7: The process of selecting mobile computing technologies from the construction information factor perspective (Chen & Kamara, 2008a)

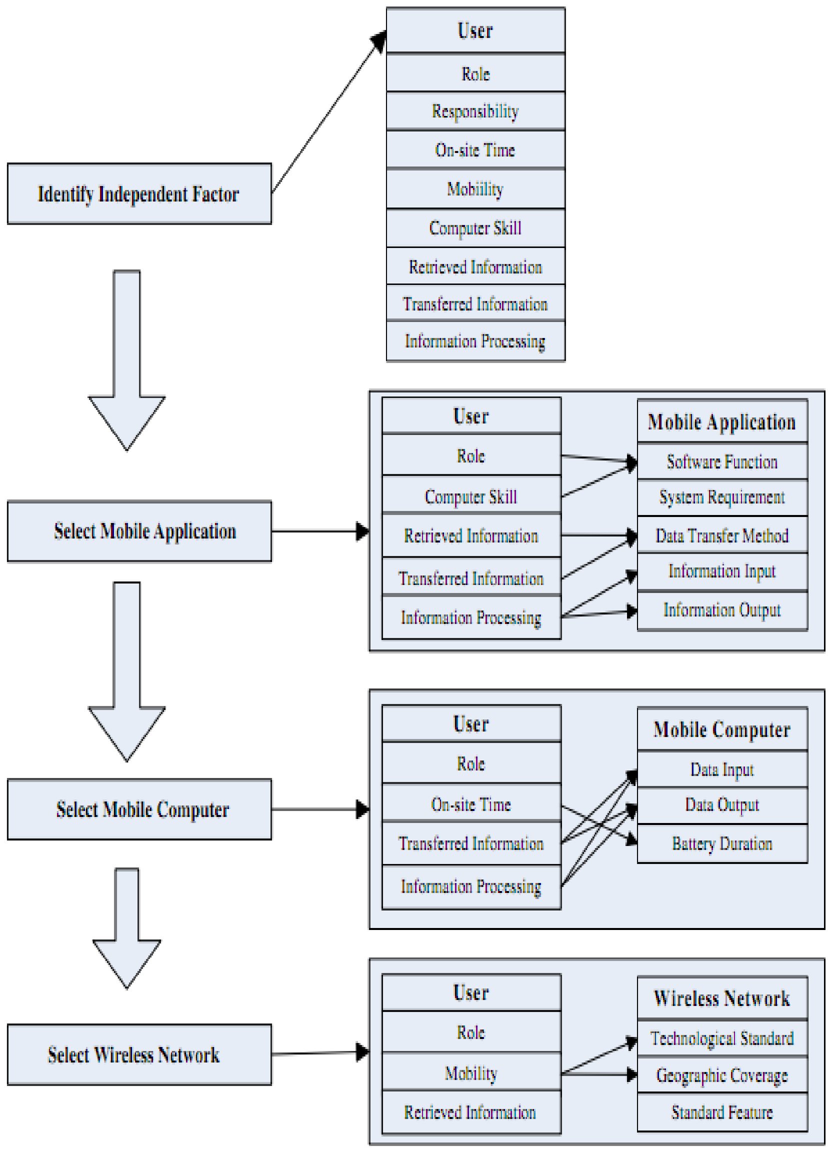


Figure 3-8: The process of selecting mobile computing technologies from the User perspective (Chen & Kamara, 2011)

Finally, the selection of mobile computing tools should take account of the physical features of a site environment, such as its rugged condition, humidity, dust, crash resistance and access to prolonged battery power to support extended use on sites. Kim et al. (2013) list three requirements of a mobile computing system to be used by site engineers:

1. A site-based computing system should be able to support site monitoring so that, at any given time, an up to date snap-shot of the construction project's work in progress is available.
2. By providing up to date information on tasks in progress and by identifying any specific problems arising, site engineers are able to locate, manage and track potential causes of completion delays as early as possible to effectively manage construction resources.
3. By sharing up to date information, the system will support collaboration among construction participants.

3.5.2. The Development of Proposed Models and Systems for Mobile Computing on the Construction Site

IT designers continue to develop software applications for smartphones and tablets that incorporate the latest generation of communication tools, such as touch screen, GPS, gyroscope, accelerometer, wireless communication capability, and so on. Kim et al. (2013) use task completion and identifiable goals as a common denominator in their review of previous studies of mobile computing; these are summarised below:

1. Studies that set out a template to illustrate how mobile computing should be used for construction.
2. Mobile computing used as a tool for location identification, or for the purposes of general construction management.
3. Mobile computing systems used to manage, detect and correct defects.
4. Systems used to improve safety and prevent or forestall serious disaster management.
5. Development of specific features of mobile computing.

Chen and Kamara (2008a) also distinguish three categories where mobile computing has been applied in construction: mobile CAD applications for interacting with drawings in construction sites; data capture applications for managing on-site information – this type of application can be subdivided into three categories, namely data capture, the barcode system, and wireless sensor system; and, project management applications for dealing with the project schedule. The outcome has been the development of a conceptual framework using mobile computing for information management on construction sites (Chen & Kamara, 2011) (see Figure 3-9).

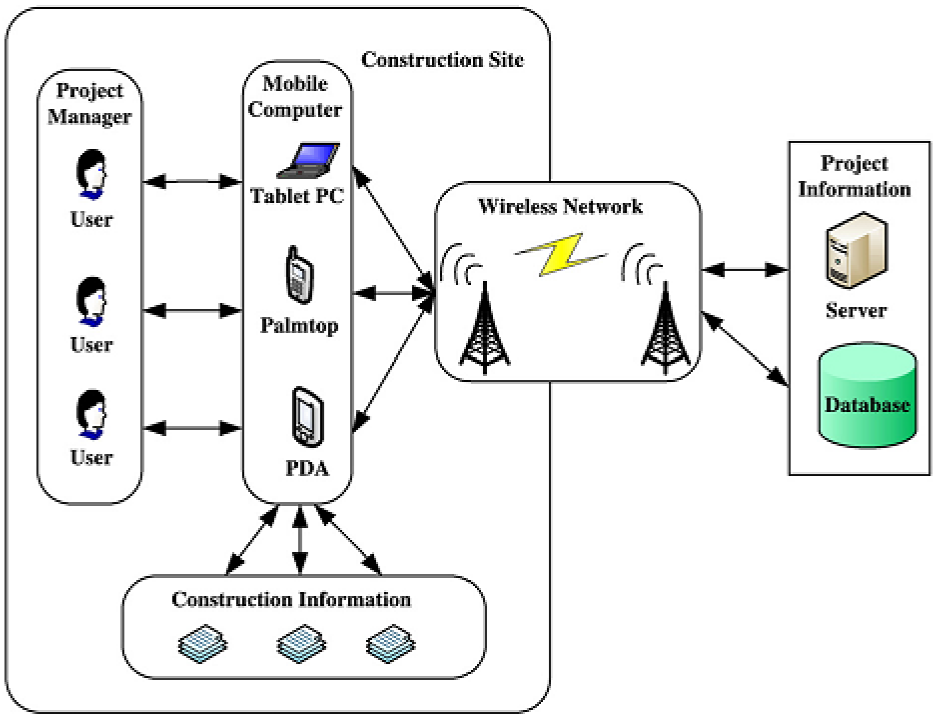


Figure 3-9: Framework for using mobile computing for information management on construction sites (Chen & Kamara, 2011).

Kim et al. (2011) proposed a mobile computing platform for location-based construction site management. Their system used Apple's iPhone SDK (Software Development Kit) to enable site management to share drawings; the proposed system was further developed and tested on an actual construction site and presented in a 2013 study (see Figure 3-10) (Kim et al., 2013). Kim et al.'s (2013) study applies the most updated smart-phone features, GPS navigation, high-resolution colour touch screens, digital cameras, sensors, and high-speed data transfer, to integrate location and construction site information and improve on-site construction management.

Kim et al. (2013) stipulate three fundamental requirements of mobile computing for effective on-site management, which are: information sufficiency, fast communication, and advantageous visualisation (Kim et al., 2013, p.417). Here, Kim et al. (2013) are arguing that the information provided must be the most desirable and important project information available, and it must be accessible and shared in real time by multiple users. A distinctive feature of their model is its ability to visualise work task information on the mobile device. By touching a "pin-pointed work task on the map, the work task information stored in the database server" becomes visible on the mobile device.

Fundamental to Kim et al.'s (2013) project is the need to be informed about the up to date status of a construction project, if engineers are to accomplish successful on-site management. The system uses an embedded calendar interface and the GPS module of the mobile device to confirm task information. It also uses a digital map, Augmented Reality technology and on-site CCTV cameras to visualise work tasks. By enabling users to track the location of work tasks and resources, these features speed up information transfer and therefore reduce costs.

Kim et al.'s (2013) proposed model (see Figure 3-10) would enable a construction manager to allocate specific work tasks to site engineers. The project manager would enter the following data: the title, description, start and end dates, and personnel responsible for the work task. When the "registration of work task is finished" and the data is entered into the database server, the relevant site engineer can check the task information on their mobile device; this, and other data, is mapped onto the "automatically derived location information of the mobile device" (Kim et al., 2013). Once the registration of a work task is complete and the information has been delivered to the database server, the site engineer responsible for the task can check the task information on their mobile device. The list of work tasks assigned to the site engineer would be illustrated on a calendar view, and more detailed task information would be available on another interface.

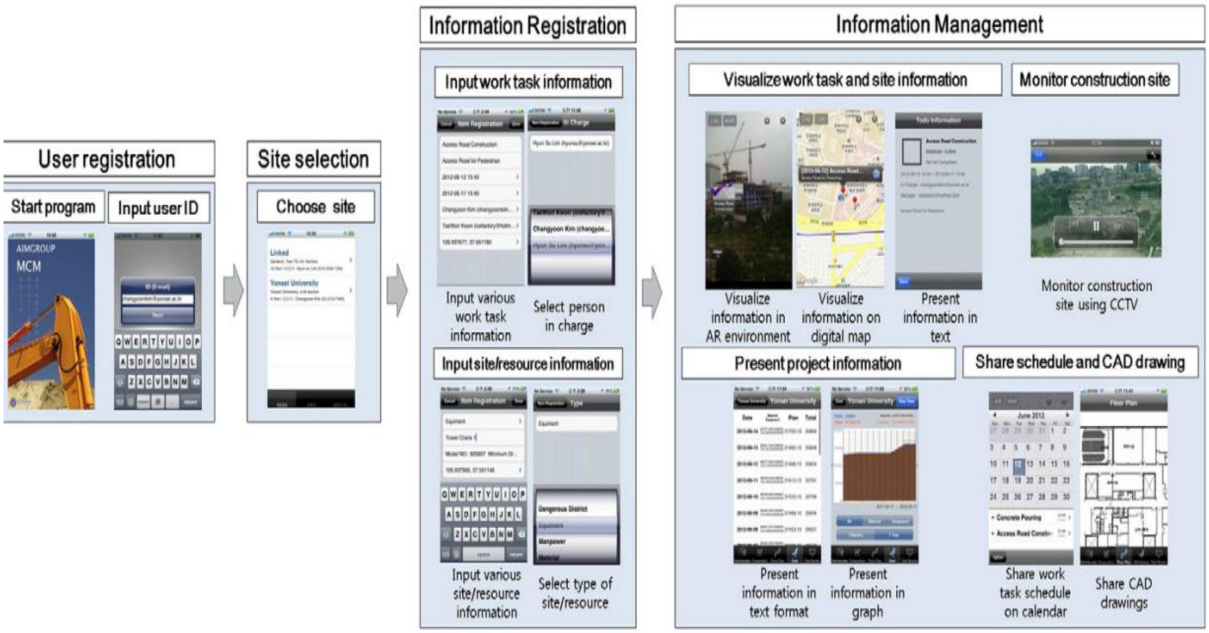


Figure 3-10: The user interface flow (Kim et al., 2013).

Kim et al.'s (2013) proposed system carries the potential for performance improvements in terms of time, cost, and quality. Real-time access to project information reduces construction time because the required travel time to visit a field office to access drawings, specifications, and plans, is reduced. A combination of the digital map and the Augmented Reality capability in mobile devices allows engineers to locate construction resources on-site without requiring significant time and effort (Kim et al., 2013). The proposed system aims to reduce construction cost because it reduces the likelihood of the need for rework by sticking to the assigned work order, and sharing information. The system also helps engineers to effectively "manage the material and equipment costs of the project," and prevent wasting the project budget. Lastly, the system aims to improve quality by reducing incidents of defects during the construction processes, and the sharing of work task information allows site engineers to become better informed about accurate construction processes (Kim et al., 2013).

Using tablets, cloud computing and just a few apps, Bringardner and Dasher describe Project Information Clouds (PICs) as a “simple way to store, access and manage project information (drawings, specs and other project docs) in the cloud,” which are then accessible from tablets and desktops, more easily updated and always relevant (2011, p.2). The authors describe the system as being much lighter, which is unsurprising, as it hosts 16,099 drawings that, using traditional methods, would be printed as hard copies; these drawings are synched to 31 iPads. The system is considered to be cheaper because all 16,099 documents are available both offline and online, and therefore do not need to be printed.

Bringardner and Dasher (2011) describe the Good Reader App as the “key missing link”, enabling all project documents to be produced in PDF format. Good Reader is an iPad app for viewing PDF files; it performs the role of syncing folders between the iPad and the cloud server. Buzzsaw, which is specifically designed for construction project team collaboration and is easily linked with Good Reader, is used as the cloud server (Bringardner & Dasher, 2011). Once all project documents are hosted on a cloud server, they can be synchronised with iPads, and a set of drawings released to the project manager on a CD, as PDFs. The PDFs are also uploaded to the cloud server; then when an iPad user presses ‘sync’ in Good Reader the added files are downloaded, giving users up to date offline access to all project information. Bringardner and Dasher describe their “powerful and simple Project Information Cloud” as a “simple system incorporating a $5 app and storage space” rented from the Buzzsaw cloud server, which can be used by appointed team members on large or small-scale projects (2011, p.7).

However, the system has two weaknesses; first, the significant amount of bandwidth required to upload the initial large amounts of data and the set of drawings; second, connecting office desktops with the Project Information Cloud demands a care-taking intervention, and efficient methods must be devised to access and edit files on the cloud that take into account the compatibility of the chosen cloud server and the version of

Windows in use (Bringardner & Dasher, 2011, p.7).

The project that Bringardner and Dasher (2011) applied the system to was a Terminal A and C renovation of Dallas/Fort Worth (DFW) Airport. The total value of the project was almost $1 US billion. The adopted system resulted in a saving of one to two hours per day for each user, because they can look at the drawings while being in the same location as the issue. In addition, the QC staff easily save two hours per day because they don't have to travel back to the jobsite office; they have a complete set of drawings everywhere they go, which reduced the printing budget by millions of dollars.

Garcia Garcia et al.'s (2014) 'Construction Programme Control' (CPC) application involves acquiring and editing job progress data, and then sending it to an office-based project manager. The information received in the office is used by the project manager to update construction progress and plan the immediate schedule. It uses Java software on a smartphone to provide a graphical interface into which progress information is entered. It captures digital images and transfers this data to the office-based PC. Construction Programme Control is an information sharing, not a communication tool; the information flow is asynchronous and unidirectional, an 'on-site inspector' uploads information from various on-site locations, which records the progress of a variety of work activities and sends this information to the project manager's office PC (Garcia et al., 2014).

Two issues are significant with regard to the tool discussed above; information is not shared with a pool of site engineers by, for example, accessing the cloud, it is merely collected and updated for the benefit of the project manager. The emphasis is therefore less on sharing and collaboration, and more on information retrieval and updating. Second, CPC uses a dedicated on-site inspector to record and edit data relating to on-site progress. It is notable that, in the United States, leading commercial contractors using a sophisticated on-site IT tool, such as BIM, feel it necessary to employ a dedicated manager responsible for its implementation within the company (Farnsworth et al. 2014). It is a matter for management's judgement whether the employment of a dedicated on-site inspector to observe and upload data relating to work practices and progress and to take overall charge of a mobile information sharing system is cost efficient. Certainly, it would relieve onsite personnel, such as engineers and supervisors, from having to perform writing and editing tasks, which is not their primary focus.

Nourbakhsh et al. (2012a) developed a construction mobile application (CMA) consisting of 13 information groups (see Figure 3-11) identified from the information survey (see Table 3-2). The functionality of the proposed application controls the entry point through the user recognition page to limit access to the system to authorised personnel only. Selected individuals are allowed to access different sections of the application based on their roles and responsibilities. For example, project managers can view, edit, and approve information, but site managers are restricted to viewing and editing.

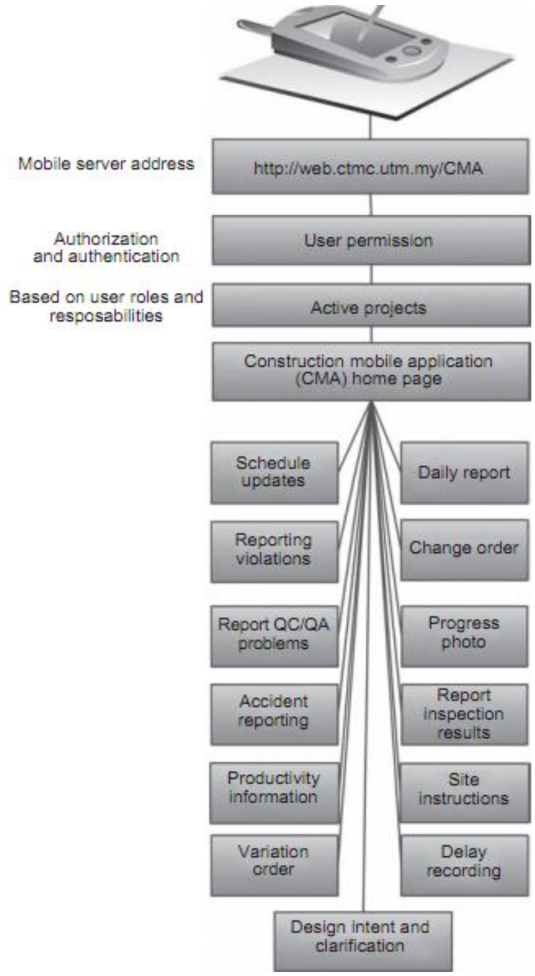


Figure 3-11: The proposed Construction Mobile Application (CMA) (Nourbakhsh et al., 2012a).

Nourbakhsh et al. (2012a) tested the CMA with 12 Master's students of construction management, not with on-site construction workers. Unlike Nourbakhsh et al.'s (2012a) study, which interviewed postgraduate students, only a limited number of studies have interviewed workers directly involved in the use of on-site IT. Moran's (2012) Master's thesis 'Assessing the Benefits of a Field Data Management Tool', drew on data from interviews with 16 project engineers, 10 project managers and 10 superintendents, with an average of 6 years' project management software experience each.

Moran's (2012) study is based on the use of field data management technology (FDMT), and is a more extensive and ambitious project than other mobile systems considered in this review because, as well as the use of BIM, it involves the participation of subcontractors, commissioning agents and projects owners. It is based on the use of field data management technology to collect construction site data and compile it into databases where it can be tracked, updated, communicated and analysed.

However, the basic functions it delivers is similar to the proposed prototype presented in this research. Moran’s (2012) field data management tool provides access to documents to which, crucially, comments can be added whilst in the field; it also has the capacity to assign tasks to project team members, and can create reports that are sent directly to specific project team members. The system uses 'punch lists' or radio buttons that allow the user to choose one item from a predefined set of options, when, for example, recording quality assurance and control issues, and safety and progress checklists (Moran, 2012).

Two studies by Nordic authors, both of which interviewed site personnel, project managers and craftsmen respectively, arrive at different conclusions. A study by Wikforss and Löfgren (2007), ‘Rethinking Communication in Construction’, draws on data from interviews with project managers to investigate web-based project networks. It considers the human, organisational and process-related factors, rather than the purely technological developments of ICT. By contrast, a study by Arnorsson (2012), ‘Optimising Information Flow on the Construction Site’, interviewed craftsmen to investigate whether the use of an ICT system on a construction site would, “reduce errors in the construction phase and increase productivity”.

Arnorsson (2012) concludes that there is a need for a change in management style to break down the barriers between managers and craftsmen, which appears to conflict with the conclusion of Wikforss and Löfgren (2007) that wirelessly extending web-based project networks to the construction site using mobile computing devices would likely not be a long-term solution for the problems that arise on construction sites. Although IT enables, “rapid communication and allows changes to be made at the last minute, it also creates new problems in such important areas as coordination, quality assurance and responsibility” (Wikforss, 2006).

Although the scope of the two studies is different, Wikforss and Löfgren (2007) also investigate web-based project networks, the communication toolkit commonly used for ICT-based project communication at the time the research was conducted. Their aim was to identify the potential such networks could offer in terms of coordinating communications within a construction project and to measure this potential against how the networks were actually used.

Wikforss and Löfgren (2007) interviewed users of web based project networks. Their study identified a mismatch between the intended purposes of web-based project networks and how such systems are used in practice; specifically, users reported that project networks, “wasted time and were overly complicated” (Wikforss & Löfgren, 2007). Users indicated that it was difficult to upload and structure documents, and to find information; it was also time consuming to log on, search for and open documents. Wikforss and Löfgren conclude that project networks were therefore not used as “active, dynamic communication networks but as passive, static archives” (2007, p.341).

The web-based IT network was primarily used as a means of document storage; such IT networks, according to Wikforss and Löfgren (2007), do not support the intensive communication required for problem-solving and decision-making processes in construction. Instead, communication was achieved through other channels, and information was more likely to be distributed in ‘real time’, that is, via informal channels, such as e-mail, SMS messaging and telephone calls. The problem is that this kind of communication behaviour provides no possibility of ensuring the overall understanding and degree of coordination that a large project requires (Wikforss & Löfgren, 2007, p.342).

Arnorsson (2012) identified a "missing link, in the digital information chain, from the contractor to the craftsmen" and set out to find an ICT solution. Arnorsson (2012) does not propose an all-encompassing IT system encapsulating all processes from design to completion. While the intention is to "improve communication between all actors on the construction site", the research is limited to an investigation of the use of an on-site ICT system to determine whether it "would reduce errors in the construction phase and increase productivity" (Arnorsson, 2012: 16). In this sense, Arnorsson is in agreement with Wikforss and Löfgren that ICT based systems play a "supportive but important role", when they are designed "according to the needs and demands of the mobile workforce" (Wikforss & Löfgren, 2007). Arnorsson further specifies that an IT system for onsite construction must be "user friendly, robust, efficient in communication and must not be time-consuming to use" (2012).

Later, Davies and Harty (2013) developed the 'Site BIM', a mobile tablet computer that accesses design information and captures work quality and progress data onsite. The system consists of five components, as shown in Figure 3-12, which include a Document Management System (DMS) for uploading and receiving information such as drawings, coordinated 3D BIM models, which are located on site office servers, maintained and coordinated by Contractor Document Controllers and synchronisation with tablet PCs for site users. Due to capacity limitations, BIM models are split into floors and/or zones for each building.

These two systems are linked with the site database, a purchased software product consisting of a 3D BIM model viewer and database functionality (Progress, Compliance and Defects) to allow characteristic metadata to be linked with objects in the model, and to use these relations to show, search and report. Project office systems support the site BIM system and tablet user systems, which include applications and data servers, network infrastructure, operating systems, and so on. The proposed system was tested in a case study, the construction of a large hospital in the United Kingdom. The results show a reduction in waste and significant savings in regard to administration and coordinating staff time.

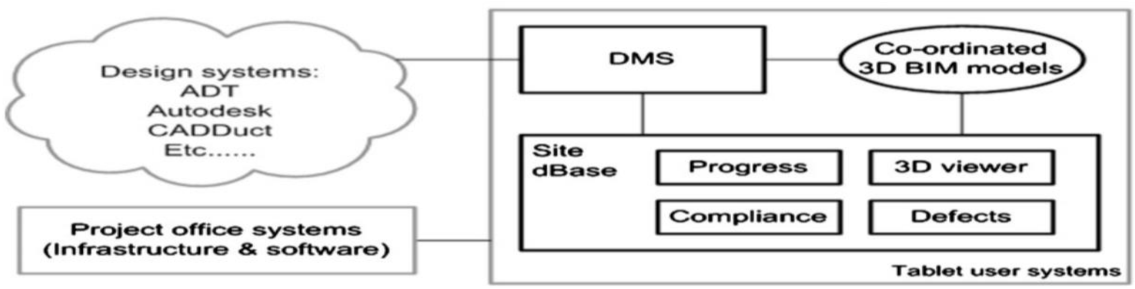


Figure 3-12: The components of site BIM systems (Davies & Harty, 2013).

In the study by Kim et al. (2013), CCTV cameras are used to visualise on-site work task information, which is shared in real time. The systems proposed by Kim et al. (2013) and Davies and Harty (2013) share progress monitoring, snagging (faults and damage) and compliance testing. Both Davies and Harty's (2013) study and Bringardner and Dasher's (2011) Project Information Cloud study, store, access, share and manage project information. In both studies, the use of tablets is pivotal to the collection and sharing of project data and the streamlining of day-to-day work. The information flow is circular in the sense that it is shared synchronously between on-site and office-based personnel.

In Garcia Garcia et al.'s (2014) prototype smartphone application, the information flow is asynchronous and unidirectional; an 'on-site inspector' uploads information from various on-site locations, which records the progress of a variety of work activities and sends this to the project manager's office PC. Similarly to Garcia Garcia et al.'s (2014)

Construction Programme Control, Nourbakhsh et al. (2012b) prioritise “simplicity, functionality, security, and affordability”. Based on findings from interviews with 12 IT professionals, Nourbakhsh et al. (2012b) identify the lack of a pool of IT knowledge as the primary reason for choosing inexpensive, easy to use software that supports collaborative teamwork; ‘DropBox’ was their user-friendly software solution.

3.5.3. The Benefit of Using Mobile Computing in Construction Site

The literature is clear about the benefits commonly associated with mobile computing; these include a reduction in paperwork, reduced repetitive data re-entry, sharing up-to-the-minute data to provide accurate real-time information, and generally improved onsite communication among the project team. These benefits are almost always set out in the form of lists; the above passages have attempted to place them in the context of the particular conditions of a construction site.

Mobile digital technology offers accurate real time data capture and delivery from site operations (see Table 3-3). It also offers: a medium for training and learning, improved collaboration, safety and security benefits with regard to the workforce, improved construction site management, design collaboration, and up-to-the-minute visualisation, sensing and tracking (Anumba & Wang, 2012). It is generally accepted that, where the will and expertise exists, the use of technologies to automate on-site data collection reduces the time required to gather information, allows the use of real-time information, decreases the response time when corrective actions must be carried out, and reduces the costs associated with late response (Nof, 2009; Kim et al., 2013).

Bowden et al. (2006) discuss the general benefits of using mobile computing technology for site-based construction. These include: reduced operation and maintenance costs; a reduction in defects; improved health and safety; reduction in waste; increased productivity; and, increased predictability. Furthermore, Sidawi (2012) lists the following benefits of using WPMS: increased productivity arising from enhanced communication between project participants; reduction in project delays; heightened awareness of project issues among all parties; and, ease of access to and retrieval of project information. Other advantages include avoiding delays due to the arrival of updated drawings and documents, reducing visits to sites and travel time to meetings, avoiding drawing mistakes, reducing time and money spent on disputes, sharing and exchanging project information, automating repetitive routine processes, and eliminating paper reports (Sidawi, 2012).

The quality, quantity and timing of information are central to the successful completion of construction projects. It has been estimated that the efficient transfer of information could reduce the cost of construction by 25% (Bowden et al., 2004). As construction projects are one-off and largely unique, experiences of earlier projects are not being documented and passed on to the next project; however, this experience may well be relevant, despite the differences between building projects, as the actual building process is more or less the same (Arnorsson, 2012).

The intensity, variety and volume of information in the construction industry means efficient information management is crucial; the literature recognises efficient information management as an important source of competitive advantage for construction companies (Kim et al., 2013). ‘Nomadic’ and ‘fragmented’ are two apt and commonly cited descriptions of the nature of site-to-site work, which ideally requires that construction workers be able to communicate effectively while remaining mobile, and have access to up-to-date project information.

The information demands of on-site construction relate to the overwhelming and distracting flow of information, from design offices to the workers on-site. Access to mobile computing provides point-of-activity workers with the ability to receive up-to-the-minute information, and to contribute effectively by updating information flows, which are crucial to any business. Anumba and Wang (2012) have briefly summarised the benefits of mobile computing in regard to decision-making:

- Mobile computing enables construction workers, many of whom are nomadic, to remain connected to their offices while undertaking work at various locations.
- Using mobile and pervasive computing technologies, workers can access information as and when it is required via an organisation's back-end systems while working on remote sites.
- The tracking and management of workers at various locations is possible, as project managers can monitor the progress of work in real time, enabling the re-direction of resources as appropriate to ensure timely completion.
- The integration of context awareness and mobile computing technologies enables the timely delivery of relevant information and services to the relevant person at the right time.
- There is scope for improved efficiency in information delivery and services, as these can be tailored to the needs of individual project team members.
- Improved collaboration, in terms of both quality of information exchange and the throughput of collaborative work, can be achieved using mobile and pervasive computing technologies.
- Real-time and context-specific retrieval of information directly addresses the problem of information overload and improves the throughput of project tasks.
- Mobile and pervasive computing technologies offer tremendous opportunities for enhanced training provision for construction workers.
- Tracking mobile construction personnel has major benefits with regard to the safety and security of the workers, particularly in hazardous, challenging or remote work locations.

Table 3-3: Summary of mobile computing benefits

The benefits	Description	Authors
Timely delivery of information	Seamlessly and effectively captures and transmits information Awareness of the current status of the work	Chen and Kamara (2008a; 2011); Anumba and Wang (2012); Wang (2012) Kim et al. (2011; 2013); Nourbakhsh et al. (2012); Son et al. (2012).
Better decision-making, reduced organisational fragmentation	Better decisions are taken because of the reliability and availability of the information to project participants	Anumba and Wang (2012).
Improved working efficiency	The input, processing and provisioning of data as well as timely access to this information	Bowden (2005); Chen and Kamara (2008a; 2011); Anumba and Wang (2012); Kim et al. (2011; 2013); Nourbakhsh et al. (2012).
Location-based construction information (Augmented Reality)	The task information is associated with the corresponding location information, which enables the construction engineers to easily understand where the tasks	Kim et al. (2011; 2013); Wang, et al. (2012)
User acceptance and perceived performance	The construction professionals perceive the advantages of mobile computing.	Bowden (2005); Son et al. (2012).
Increased productivity	The managers can reduce the time required for organising information, and the foremen can be sure that they are executing the work in accordance with the latest information	Arnorsson (2012); Bowden (2005); Chen and Kamara (2008a; 2011); Anumba and Wang (2012); Kim et al. (2011, 2013); Nourbakhsh et al. (2012); Son et al. (2012).
Improvement to the existing process	Improving processes provides construction engineers with unprecedented opportunities to improve existing processes and innovate to improve wasteful processes in on-site construction management	Bowden (2005); Chen and Kamara (2008a; 2011); Anumba and Wang (2012); Wang, (2012); Kim et al. (2011; 2013); Nourbakhsh et al. (2012); Son et al. (2012).
High mobility	Provides site engineers and foremen with the ability to perform better and move between site locations and site offices	Anumba and Wang (2012); Kim et al. (2013).

Tracking and management of workers	Monitors the progress of work in real time, enabling the re-direction of resources as appropriate to ensure timely completion, as well as the safety and security of the worker, particularly in hazardous, challenging or remote work locations.	Anumba and Wang (2012).
Improved collaboration	In terms of both quality of information exchange and the throughput of collaborative work.	Anumba and Wang (2012)
Enhanced training provision for construction personnel	Arises from the integration of Augmented Reality with site information.	Wang et al. (2012).

3.5.4. The Barriers and Challenges of Using Mobile Computing on the Construction Site

The literature is in broad agreement that mobile technology has the potential to improve construction site efficiency and productivity, and help solve communication and coordination problems. There is less agreement concerning the reasons behind why mobile computing has not been more widely applied, and which particular barriers have slowed or prevented its adoption. Saidi et al. (2002) assess the nature of barriers to the use of mobile computing in construction, and distinguish between the technical limitations of the hardware and software and, on the other hand, the largely behavioural and attitudinal barriers, which they describe as characteristics of the construction industry:

- Construction industry characteristics: these barriers include the physical jobsite conditions, such as temperature, humidity, dust, and so on, and organisational issues, such as industry fragmentation and low tolerance of risk.
- Limitations of mobile computing hardware: these technical limitations include screen size, screen visibility, processing capability, and input methods.

3.5.4.1. Construction industry characteristics

One characteristic frequently referenced in the literature is the conservative culture of construction firms and their resistance to change (Bloomberg, 2013; Al-Tami, 2015; Son et al., 2012; Nof et al., 2009). In comparison with manufacturing, aerospace, or the automobile industries, construction is considered slow in terms of technological progress. When considering the implementation of onsite mobile computing, this research will avoid treating the industry as homogenous, as it in fact ranges from multi-national, multi-disciplinary consultancies to much smaller single location entities (Davies, 2008). In terms of size, income and the numbers employed, there is considerable variation between firms. BIM, for example, is only used for high value, complex and high risk projects (Farnsworth et al., 2014).

One consequence of a multi-national, and therefore multi-cultural, workforce is a context of multilingual communication. Dainty et al. (2006) associate the fragmented structure, culture and technical nature of the construction industry with a variety of formal and informal languages that have emerged around its processes and people. If the contractor company has diverse employees, then language becomes an issue, which can lead to misunderstandings, confusion or embarrassment among employees. Typically, the formal language of contractor companies will be the official language of the country they are working within; informal languages may be spoken, according to the nationalities of the majority of labourers, engineers, and other employees.

However, even when workers speak the same language they have problems with the vocabulary and glossaries; for example, Arabic is the first language of several countries, but modes of expression and semantics differ from one to another, meaning that jargon and semantics is another issue contributing to the problem of language. Dainty et al. (2006) indicate that a lack of standardisation in size, quality and commonality of meaning in vocabularies means that individuals define similar processes differently; the, terminology and semantics used by mobile workers must be universally understood to avoid misunderstanding and confusion.

Nof describes construction as an “antiquated industry” that pays modest attention to research and development (2009: 1069). The assumed endless availability of cheap labour and the focus on cost reduction and short-term efficiency have limited the rationale for technological innovation (Nof, 2009). The main problems associated with manual and labour-intensive processes are delays in obtaining, processing, and accessing information, as well as inconsistencies and inaccuracies in the information itself, resulting from its manual entry (Son et al., 2012). In a UK Commission report (2013) into technology and skills in the construction industry, emerging technologies are perceived, in some cases, to be high-risk, as they are “largely regarded as untried and untested, so it can be difficult to raise finance for projects” (Vokes & Brennan, 2013, p.52).

The industry is still widely considered “traditional,” conservative in both business practices and construction methods and processes (Al Surf et al., 2013, p.100). Companies are seen to be reluctant to change existing practices, despite the efficiency and time and cost savings offered by the newer information technology now available (Nof et al., 2009). Peansupap and Walker (2005) argue that this resistance to change is due to engrained work habits acquired over time, which are a potential constraint on the industry’s willingness to adopt innovative IT solutions. Wikforss and Löfgren (2007) also describe general resistance to the introduction of new technology within the industry. Any IT solution must take account of this resistance to change amongst management in the industry, which is commonly encountered when different professional groups seek to defend their own interests (Wikforss & Löfgren, 2007). As such, Peansupap and Walker (2005) recommend that any IT innovation should be conceived so that it is not disruptive to conventional work practices.

Just as technology has developed, so too have attitudes toward its use. Section 3.4 explained how the increased user-friendliness of mobile phones has diluted resistance to their use in the workplace. The multi-functional smartphone has paved the way for its use as a mobile IT tool in the workplace. Evidence that managerial resistance is gradually being replaced by a general acceptance of IT usage on-site can be found by comparing the responses of Danish construction managers interviewed in 2009 and 2012. A Danish Construction Association survey, carried out in 2009, found that only 9% of managers believed it was "very important" to have access to a project web system, and only 15% of the project managers had used an on-site project web system themselves (Arnorsson, 2012, p.43).

The same 2009 survey asked 110 managerial staff if the craftsmen in their company had easy access to on-site IT. Only one manager said that his craftsmen had access to IT, and 49% of managers believed that the craftsmen should not have such access. This viewpoint was in contrast to the views of on-site workers themselves; when craftsmen working on site were asked if they would use an accessible IT system on the construction site, 73% answered 'Yes', 15% answered 'No' and 11% weren't sure. By 2012, Arnorsson (2012) concludes that a "general positivity and acceptance towards increased use of IT," was observable, and that a change in management style would "break down the barriers between managers and craftsmen" (Arnorsson, 2012, p.45).

Sidawi and Omairi's (2010) investigation into barriers to the effective implementation of a web-based project management system emphasises attitudinal and managerial impediments. They identify staff resistance to change, work methodology and processes, the lack of an IT infrastructure among construction companies and their supply chains, inadequate computing proficiency levels amongst senior management and staff, concern about the returns on investment, a preference for old-style paper-based communication and management attitudes as issues that any introduction of a new IT system must address.

Garcia Garcia et al.'s (2014) 'Construction Programme Control', which collects on-site data measuring job progress and job quality and sends it to an office-based project manager, highlights company cultures that favour traditional methods as a barrier that needs to be overcome. Overcoming deep-seated cultural practices and motivating the project manager and site engineers who will use the new technology to change work methodology and processes is likely to "create resistance, perhaps from older, more experienced and more influential managers who have become comfortable using traditional pen-and-paper methods (Garcia Garcia et al., 2014, p.97). A "recurring observation" in Moran's study of a field data management tool is that "younger construction management" personnel appear to use new technology "more enthusiastically and effectively than older users" (2012, p.148).

Alshawi et al. (2003b) discuss the difficulty of measuring return on IT investments, as companies are too inflexible in their concentration on bottom-line financial savings to properly measure its value. The capability of IT to deliver non-financial benefits, such as improved flexibility and increased responsiveness, is not easily factored into the savings/benefit equation. These practices have caused organisations to fail to understand the need for an active policy of business benefit recognition. Resistance to IT investment has been based on the belief that IT has only indirect benefits; that is, that IT merely enables the conditions, or creates a capability, from which benefit can be derived. In other words, the cost benefits implicit to IT become apparent when construction workers modify their work processes and improve their skill sets as a direct result of their use of IT, but these are largely intangible and immeasurable benefits. Nevertheless, having clear views and policy aims relating to how the IT capability will be used makes it easier for a construction company to measure the true benefits IT provides, such as more efficient and transparent work processes (Alshawi et al., 2003b).

Central to the recognition of the benefits of IT is the distinction between outcomes and benefits. An outcome is the result of introducing a new IT system; a benefit is what is subsequently derived if the new capability is properly utilised. For example, field engineers have the experience to be able to spot non-conforming work; if the field engineer spots a faulty product, or the product does not match the design, the engineer can raise new issues and use a comment facility to make clear which company or individual is responsible and assign a priority level to the issue. However, if these comments are not followed up, and no action is taken, no benefit is accrued. Several studies (Eadie et al., 2013; Farnsworth et al., 2014) have reported that applications are not used because firms are unable to determine the financial benefit to the project.

A serious systemic barrier to investment in IT is difficulty in assessing and apportioning the cost savings, which are cited as the chief reason for the use of IT. Son et al. acknowledge that it can be “difficult to measure the effects of IT use on organisational performance in an objective manner” (2012: 83). The cost benefits are enjoyed by the project as a whole, but the advantages to any one participant are not easily quantified. Savings arising from IT usage are difficult to assess and apportion in this way because they are reflected in terms of time savings and increased efficiency, but these are consequences that may also be affected by other factors simultaneously at play.

Generally, project management practice and research defines successful IT innovation in terms of “pre-established time/cost/quality criteria” (Davies & Harty, 2013, p.21). However, Davies and Harty show that project participants also apply “other behavioural or organisational criteria,” which are liable to change over the course of a project lifecycle (2013, p.21). The authors refer to a study in which participants assessed project success not merely in “terms of cost, time and technical performance,” but also in relation to the “absence of negative experiences” and the “degree of take-up of the technology and how it supports and automates existing processes” (Davies & Harty, 2013, p.21).

The difficulty in identifying clear-cut, company-specific benefits contributes to another managerial impediment to the development of IT in the industry. Because mobile software is, by definition, applied on-site, its benefits will be most evident at the project level. However, while the impetus for development and innovation is most likely to emerge from project-focused needs, it is at the managerial or executive level that decisions regarding medium and long-term investment in IT are taken. Eadie et al. (2013) cite the lack of immediate benefits from projects delivered to date as one reason for management's reluctance to utilise BIM.

Davies and Harty (2013) examine the oppositional tension between project-focused needs and IT investment decisions taken at the managerial or executive level. They carried out a case study of a real-world project, building and refurbishment work across two large city-centre hospitals, to implement BIM-related tools and tablet personal computers for mobile computing use on-site during the construction phase.

Site workers used personal mobile computers to access design information and to capture work quality and progress data whilst on-site. The application of mobile computing tools was delivered through an "exploratory and emergent development process of informal prototyping" (Davies & Harty, 2013). This means that mobile computing was successfully implemented by co-opting a repository of IT skills into the construction project "through personal relationships and arrangements rather than formal processes," and "implementation was driven by construction project employees rather than controlled centrally by the corporate IT function" (Davies & Harty, 2013, p.16). The researchers questioned the received wisdom that support from top management is fundamental to the success of IT innovation in construction, and argue that it is important to distinguish between the project and the permanent organisation when analysing IT adoption. Furthermore, large organisations typically have the space and scope to experiment and innovate (Davies & Harty, 2013, p.22).

In the case of the hospital refurbishment, the limited role of the firm's top management and IT department reflects the project-led nature of the innovation. Davies and Harty's (2013) research questions implicit assumptions about the role of projects in construction innovation, and emphasises how informal methods and strong personal working relationships can sidestep top level managerial resistance to IT innovation. The authors make a convincing case that the "dynamics within the innovation project" and the "social and organisational context in which it operates" strongly influence the way IT implementations unfolds (Davies & Harty, 2013, p.18).

Davies and Harty's (2013) 'exploratory' project-based and project-led implementation opened the way for "new technology development and process and organisational changes". Their findings with regard to the oppositional roles of the construction project and the parent firm's top management contradict the notion that it is "always firms that adopt innovations and then apply them on projects", and challenges the axiom that "successful implementation of new and innovative Information Technology in construction requires the development of strategic implementation plans prior to IT project commencement" (Davies & Harty, 2013, p.22).

Davies and Harty (2013) expose the weakness implicit in making generalisations when considering the role of IT driven projects in construction innovation. They challenge the generalised and unquestioned assumption that "firms are single, definable entities," where the reality is that in "project-based firms in particular, project teams may have little contact with the firm's senior management" (Davies & Harty, 2013, p.16). In addition, Son et al. (2012,) conclude that user perceptions of the software are a reliable indicator of the intent to adopt mobile computing devices, and that user satisfaction is influential in determining their continued use. Construction professionals' satisfaction with mobile computing devices is more likely to be affected by a belief in the utility of the devices being used, rather than any perception of their user friendliness. Son et al. (2012) also conclude that determinants of perceived usefulness, such as "social influence, job relevance, and top management support," and determinants of perceived user friendliness, such as "training and technological complexity," are pivotal factors predisposing users to implement mobile computing devices in the construction industry (Son et al., 2012, p.81).

The overall perception is that 'builders', as a group are not computer users, although adoption can be encouraged with appropriate support. This takes the form of formal training, publication of self-help guides and one-to-one support and coaching. 'Training' is not a one-off event; ongoing support is needed, not only to assist but also to 'bed-in' the use of technology (Davies & Harty, 2013, p.20). A focused and user-friendly system with a narrow scope and clearly defined aims of sharing and retrieving information would suit a Saudi context. According to Nourbakhsh (2012b), the technical solutions for recording and sharing information are most likely to involve smartphones, tablets and cloud computing. Garcia Garcia et al. (2014) state that smartphones and tablets, when used correctly, are useful tools for project managers, engineers, architects, and subcontractors.

Froese (2010) states that the full potential of mobile devices will only be realised when changes in the work tasks, attitudes and skill sets of project participants consolidate the success of investing in mobile computing. Furthermore, Wikforss and Löfgren, highlight the influential role of the potential operatives within the user organisation, and how important collaboration is to the adaptation process because new technology is "seldom a perfect fit" with the user environment; "collaboration, communication and feedback between users and developers are often critical in achieving the proper fit between technology, organisation, and users" (2007, p.344).

User involvement in the technical development and implementation of IT communication tools plays an important role in ensuring their long-term success (Wikforss & Löfgren, 2007). Peansupap and Walker suggest that open discussion within a construction company is an "important variable supporting ICT diffusion" (2005, p.202). The value of an open environment is that it encourages suggestions for improving and adapting unfamiliar IT solutions. Open discussion also helps managers to better understand initial problems experienced by those operating IT applications, because it encourages the articulation of strategies to confront and remove potential deficiencies and allows suggestions to be made for improvement (Peansupap & Walker, 2005). If the values and management structure of the organisation encourage open discussion this aids in the reporting of system difficulties, which will make the system more efficient, increase its acceptance and improve productivity.

3.5.4.2. Technology challenges and limitations

Generally, construction professionals acknowledge the utility of mobile computing technologies; however, there is some uncertainty in regard to how to implement them, and their complexity is a concern (Son et al., 2012; Bowden, 2005; Kim et al., 2013; Davies & Harty, 2013). Son et al. (2012) conclude that construction professionals' perception that mobile computing devices have real utility in the workplace is a more important factor in determining their acceptance and adoption of these than their user-friendliness is. This is significant because continual improvements to state-of-the-art mobile computing technologies are likely to further increase their utility, and therefore their acceptance in the workplace.

Research carried out after 2010 is generally less focused on details, such as the limitations of screen size, and the keyboard, and, more generally, is less concerned with the limitations of technology than research carried out before 2010. For example, in a study carried out by Bowden (2005), participants were least satisfied with using smaller screens on mobile for viewing and annotating drawings prior to 2005; this study concluded that an alternative way of delivering drawing information in the field was required, and either devices or drawings needed to be adapted to improve their delivery by electronic means. In 2002, Saidi et al. concluded that the technical limitations of "screen size, screen visibility, processing capability, and input methods were insurmountable barriers to the use of mobile computing in construction". Nevertheless, these technical limitations were overcome by advances in hardware development.

A study by Bowden and Thorpe (2002) asked 17 construction workers to assess the portability, screen clarity, appearance, and ease of data entry on portable devices. In a review of their study, Dainty et al. (2006) state that, although the operational shortcomings exposed by such studies have been superseded by advances in hardware development, even this thirteen year old study found that site-based staff are prepared to use devices to communicate with the wider team.

Chen (2008) discusses the obvious and, given the size of mobile devices, unavoidable risk of loss or damage. The possibility of breakdown or damage to the device can result in "all the work that had been carried out since the last synchronisation" being lost. Bowden cites the limited battery power of mobile devices, especially where staff are "working an 8-10 hour day, as an inconvenience that "could create reluctance to rely on the device" (Bowden, 2005).

The key challenges of mobile computing in construction, as discussed by Anumba and Wang (2012), include the complexity and cost of developing mobile applications, the need to focus on user requirements, the need for integration with existing applications, the adaptation of content to fit multiple device types, and the choice of wireless technologies. Kim et al. (2013) cite the impact of data input and output methods, in terms of the usability of devices, as a limitation to their use on construction sites, where efficient and effective information input can be affected by difficult conditions.

As a result of the fast development of the mobile device, data input methods now include keyboard, touch screen, camera, and video recorder, as well as data output, which depends on the construction information format and the mobile capabilities. These are generally displayed in one of two ways, which are "the screen for the information formats of graphics, text, images, and a speaker, for verbal communication" (Chen & Kamara, 2011). This means that, generally, data output is affected by the "screen size, visibility and resolution," and that in terms of the size and weight of the mobile device, it may become too small to handle with larger hands, or to heavy to carry (Chen & Kamara, 2011).

Data input and output methods also affect the battery life of the mobile device, which must be able to function over a long period of time if it is to support the outdoor user during on-site construction (Bowden, 2005; Kim et al., 2013). Half of Bowden's (2005) survey respondents did not believe that hand-held computers could be used on site, and thought that they would not stand up to the harsh site environment. Bowden (2005) further indicated that when personnel become too reliant on the device, such that if it were to break down they would have to return to pen and paper and the necessary protocols would no longer be available. Thus, technical support plays a vital role in overcoming this, and includes practical aspects of user requirements, such as "specialised instruction, guidance, coaching, and consultation in using technology" (Son et al., 2012). The relation between the usability of mobile computing and the technical support is equable; the greater the quality of technical support, the higher the probability of a successful adoption of mobile computing.

The rapid development of smartphone capabilities has made available opportunities for mobile information access and computing available to the average worker that that were unheard of even five years ago. The current generation is the first generation able to enjoy and make use of ubiquitous mobile computer connectivity. However, smartphone use may be constrained by their unsuitability for construction site work environments

(Pierce et al., 2011). The core concept of mobile computing in a working context is the opportunity it gives workers to, “roam seamlessly with computing and communication functionalities in an uninterrupted way” (Pierce et al., 2011).

For the construction industry, the choice to use mobile computing devices is optional. The literature suggests that their acceptance, from the end user perspective, will be influenced by their utility (Son et al., 2012); that is, how well they ‘do the job’. The evidence gathered through interviews and questionnaires also indicates that their acceptance will be further influenced by perceptions of their user friendliness, in other words how easy they are to use (Arnorsson, 2012). In the medium-term, smartphones may become the accepted management tool for managing work tasks, in which case, their acceptance in place of office PCs will, from a management perspective, be provoked by the need to remain competitive.

At the 2010 Mobile World Congress, the CEO of Google forecast that in three years’ time, desktops will be irrelevant and that Google’s future business strategy will be seen through a mobile lens, centred on cloud computing and connectivity to create new business models. By contrast, Pierce et al. (2011) contend that smartphones are more suited to consuming than producing information and are not yet for a substitute for computers. Their application is limited in unwelcoming environments such as construction sites because of the more “effortful text entry,” and slower reading speeds compared to computers. Pierce et al. (2011) conclude that although security mechanisms are a significant barrier to wider smartphone use in business, these can be overcome.

The barriers to smartphone usage include irritation at using small screens, making it more difficult to quickly and easily comprehend large amounts of information (Pierce et al., 2011). However, since this observation was made, tablets have become a viable alternative option; requiring the user to compromise between portability and legibility, according to the tasks being performed. There is evidence of a reluctance to use mobile devices to respond to emails or compose documents; Barkhuus and Polichar (2010) ascribe this reluctance to the difficulty of typing on smartphones, despite the availability of hard keyboards and word completion algorithms.

Barkhuus and Polichar (2010) acknowledge that the multifunctional mobile phone confounds historical notions of human-computer interaction in the sense that the design of the small interface was once considered a barrier to its use in a commercial work environment. However, the limitations of its relatively small interface have become less important as screen size has increased, and apps have enhanced its multi-functional characteristics and expanded its capacity to add and remove functions in the workplace. Barkhuus and Polichar (2010) identify the unique characteristic of the mobile device as its ability to select and blend functionality in the workplace; the authors consider its ability to mix, match and connect different apps as the key to the smartphone's future success in the workplace (Barkhuus & Polichar, 2010).

In 2013, 102 billion apps were downloaded (Shelton, 2013); the increase in the popularity of apps reflects an important change within the design direction of mobile interactions, which favours improving software over improvements to the hardware specification of devices. This change in direction indicates that a temporary level of stability has been reached in terms of physical factors and basic input and output capabilities, with the focus now on applications and content (Kjeldskov cited in Soegaard et al., 2014).

Despite increasing usage of mobile computing, exploiting its potential is complicated due to problems including, "resource scarcity, frequent disconnections, finite energy and low connectivity and mobility" (Fernando et al., 2013, p.97). Fernando et al. (2013) argue that mobile cloud computing can help address these problems, and link the rising value of the market for cloud-based mobile applications, which was worth $9.5 billion in 2014

(Fernando et al., 2013), to the increasing use of mobile computing in commercial settings.

Commonly used applications on the construction site, such as the use of sensors to obtain a GPS reading, for example to confirm the location of site work, are energy expensive, and applications that require extensive processing, such as image and speech processing and the Augmented Reality used in the model proposed by Kim et al. (2013), demand high computational capacities that restrict performance. Writing in 2013, Fernando et al. forecast that limitations in battery design made it “unlikely that these problems will be solved in the future” and that, far from being “temporary technological deficiencies” the problems preventing the realisation of the full potential of mobile computing were “intrinsic to mobility” (2013, p.84).

According to Nourbakhsh et al. (2012b) and Fernando et al. (2013) mobile cloud computing helps overcome the resource limitations of mobile devices by providing “seamless and rich functionality,” meaning they could become the dominant model for mobile applications in the future (Fernando et al., 2013, p.103). One requirement is a quick start up process, as mobile devices are not as robust as desktop PCs and faults occur more frequently (Fernando et al., 2013). Implicit to the uploading of sensitive data to the cloud is the surrender of direct physical control over the data; it is therefore imperative that an effective recovery insurance mechanism is in place to retrieve lost data in the case of technological failure or other malfunction.

Due to the inherent limitations of the hand-held device, mobile databases are not able to replicate the extensive functionalities of a traditional database. Particularly in the context of the mobile cloud, this research argues that any proposed model must be easy to use and should store and share a limited amount of information, which would match the requirement of any mobile database; it must be lightweight, have the ability to download and use data from a remote repository, and must also be able to synchronise the modified record of onsite work progress when the network becomes available again.

Table 3-4: Summary of barriers to mobile computing

Barrier	**Description**	**Authors**
Organisation fragmentation	The effect of high level of entities in the project on the adoption of mobile computing	Davies and Harty (2013); Wikforss and Löfgren, 2007
People's working habits	The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.	Peansupap and Walker (2005); Wikforss and Löfgren (2007); Sidawi and Omairi (2010); Davies and Harty (2013).
Multicultural	The diversity of multinational employees affects mobile implementation	Loosemore and Lee (2001); Ochieng and Price (2009).
Social influence	The social influence over users' adoption of mobile computing	Bowden (2005); Son et al. (2012); Davies and Harty (2013).
Multiple languages	The diversity of project members' spoken languages affects the adoption of mobile devices.	Dainty et al. (2006); Loosemore and Lee (2001).
Management processes	The effect of existing management practices that cause reluctance to change by implementing mobile	Nof et al. (2009); Wikforss and Löfgren (2007); Peansupap and Walker (2005); Arnorsson (2012); Sidawi and Omairi (2010); Garcia Garcia et al. (2014); Davies and Harty (2013); Sidawi (2012); Bloomberg (2013); Al-Tami (2015); Son et al. (2012); Davies

		and Harty (2013); Froese (2010).
Training support	The availability of training support for the uptake of mobile computing.	Vokes and Brennan (2013); Son et al. (2012); Davies and Harty (2013).
Attitudes - acceptance of IT	The effect of users' attitudes on the acceptance of mobile adoption	Arnorsson (2012); Son et al. (2012); Anumba and Wang (2012); Sidawi and Omairi (2010); Moran (2012); Froese (2010).
Support from top management	The effect of top management support on the uptake of mobile computing	Davies and Harty (2013); Son *et al.* (2012).
User requirements	The effects of user requirements on the adoption of mobile computing.	Son et al. (2012); Anumba and Wang (2012); Wikforss and Löfgren (2007); Peansupap and Walker (2005).
Repository of IT skills	The effect of staff IT skills and proficiency in utilising mobile computing.	Davies and Harty (2013); Froese (2010); Sidawi (2012; Bowden, 2005); Sidawi and Omairi (2010).
Data security	The data security issue affects utilising mobile computing	Pierce et al. (2011); Fernando et al. (2013).
Battery power	The effect of battery consumption on utilising mobile devices	Bowden (2005); Kim et al., (2013); Fernando et al. (2013).
Device performance	The effect of a lack of IT infrastructure on mobile adoption	Sidawi and Omairi (2010); Fernando et al. (2013); Kim et al. (2013).
Technical support	The availability of technical support in the uptake of mobile computing	Wikforss and Löfgren (2007); Son et al. (2012); Sidawi (2012); Nourbakhsh (2012b); Chen (2008).
Screen	The effect of screen clarity on	Saidi et al. (2002); Bowden and

visibility and resolution	presenting the project information	Thorpe (2002); Bowden (2005); Chen and Kamara (2011); Pierce et al. (2011).
Input and output methods	The data entry and display approaches affect the adoption of mobile computing.	Saidi et al. (2002); Bowden and Thorpe (2002); Kim et al. (2013); Chen and Kamara (2011); Bowden (2005); Pierce et al. (2011); Barkhuus and Polichar (2010).
Screen size	The effect of screen size on the data that is displayed.	Saidi et al. (2002); Bowden (2005); Pierce et al. (2011); Barkhuus and Polichar (2010).
The device capability	The device capabilities that impact on the utilisation of mobile devices.	Pierce et al. (2011); Barkhuus and Polichar (2010); Fernando et al. (2013).
Application complexity	The effect of technological complexity on the adoption of mobile computing.	Son et al. (2012); Bowden, (2005); Kim et al. (2013); Chen (2008); Anumba and Wang (2012); Arnorsson (2012).
Terminology and semantics	Diversity of terminology and semantics among project members' affects mobile device adoption.	Dainty et al. (2006).
Size and weight of the device	The portability (size and weight) of the device affects the adoption of the device	Bowden and Thorpe (2002); Chen and Kamara (2011); Pierce et al. (2011).
Physical jobsite conditions	The effect of the site conditions (e.g. temperature, humidity, dust) on the utilisation of mobile devices.	Saidi et al. (2002); Bowden (2005); Pierce et al. (2011).

3.6. Summary

This review has assessed the literature's response to the assertion that mobile devices represent "the missing link in Construction Information Technology" between actual operations onsite and the site office. Scholars agree that effective communication is essential to efficient operations, which is an outcome from Objective 1. The review uses a thematic approach to trace the evolution of the communication and information needs of site-based construction workers, which is driven by Objectives 3 and 4 in Section 3.4, and which will be addressed in the next chapter, through the mechanisms of both the case studies and the questionnaire. It also examines the literature's treatment of problems associated with traditional record keeping, including message distortion, information gate-keeping, information overload, how the demands of collaborative working and the disintegration of construction worksites and personnel affect communication, and the role of multi-cultural and multi-lingual workforces.

As required by Objective 1, this chapter also compares and contrasts, in some detail, several proposed models and systems of mobile computing. The literature review relies on recent research to summarise the most common paper-based tasks carried out in the field, and establish which communication processes would benefit most from the application of mobile computing. It examines two important aspects related to Objective 2, which are the reported benefits and the barriers associated with mobile computing, which are categorised as technical limitations of the hardware and software and, on the other hand, the largely behavioural and attitudinal barriers considered characteristic of the construction industry. These barriers are essential in this research, as the questionnaire will ask first about the generality, and then the interviews will elicit more in-depth information, as stated in the following Chapter, in Sections 4.6 and 4.8. This data will be presented in Chapters 5 and 6, and discussed in Chapter 7, which helps to develop the framework driven by Objective 5 and presented in Chapter 8.

Chapter 4: Research Methodology

4.1. Introduction

This chapter presents the research methodology used to collect the data and address the research questions. The chapter begins with an important section, which contains a description of the research design followed by a description of the different stages of the research process (see Figure 4-1). This chapter presents and justifies the method adopted to implement and validate the proposed framework strategy for mobile computing to manage and control construction-sites in the Saudi construction industry.

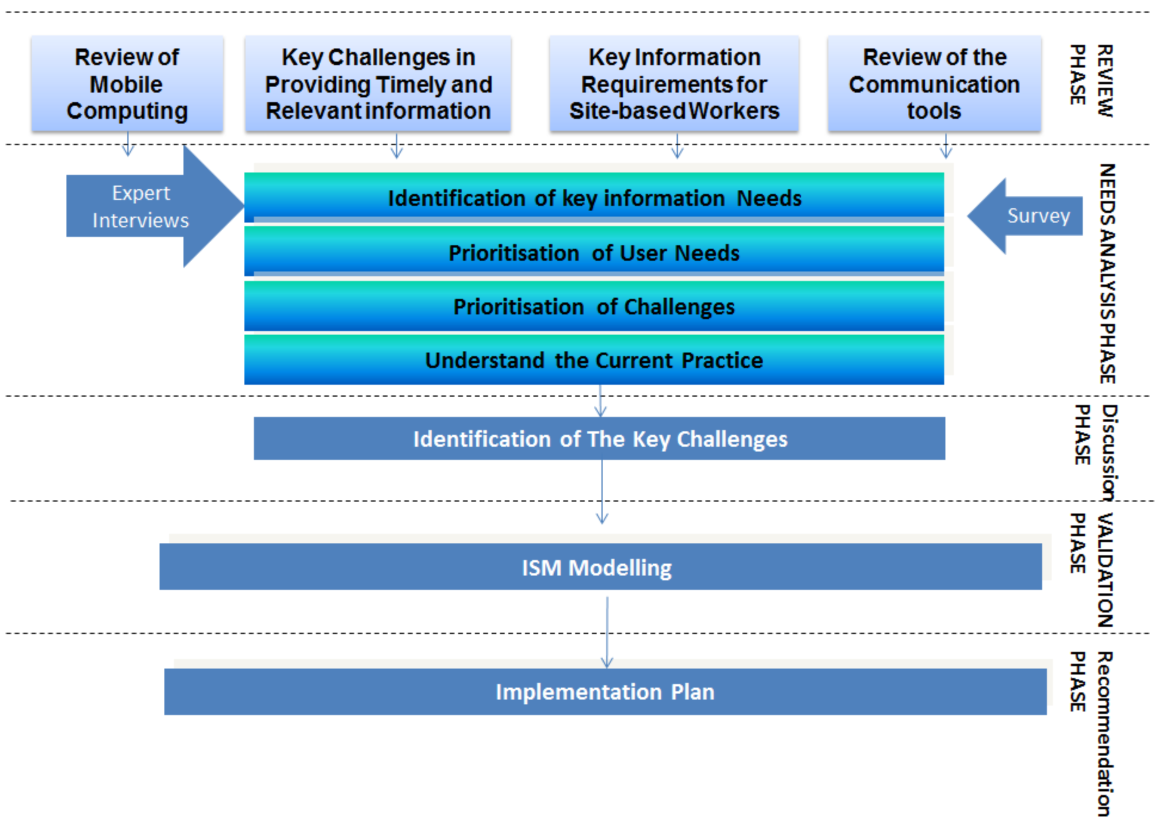


Figure 4-1: The key steps in the research process

4.2. Research Design

The Oxford Dictionary (2012) defines research as “the systematic investigation into study of materials and sources in order to establish facts and reach new conclusions.” Research methodology can be defined as “a way to systematically solve the research problem” (Kothari, 2004). The methodology, therefore, is the chosen means of collating and analysing data to provide answers to the ‘why, what, from where, when and how’ questions (Scotland, 2012). The research design may be defined as the “conceptual structure within which research is conducted; it constitutes the blueprint for the collection, measurement and analysis of data” (Kothari, 2004). Different research design models can be applied including the Research Onion, the Nested Model (Kagioglou et al., 2000) and Research Design Elements (Crotty, 1998) (see Table 4-1). These models are graphic representations, which organise the research methodology and guide the researcher in the implementation of data collection methods that are most suited to the research. In addition, it directs the readers through the methodology in a simple way, so that the readers can easily achieve a good understanding of the methods adopted for this research. Saunders et al.’s (2012) comprehensive Research Onion model is the model used for this research (see Figure 4-2).

Table 4-1: The Comparison of the Three Research Design Models (Saunders et al., 2009; Crotty, 1998; Kagioglou et al., 2000)

Research Onion	Research Design Elements	Nested Research Model
Research Philosophy	Epistemology Theoretical perspective	Research Philosophy
Research Approaches		
Research Strategies	Methodology	Research Approaches
Choices		
Time Horizons		
Techniques and procedures	Method	Research Techniques

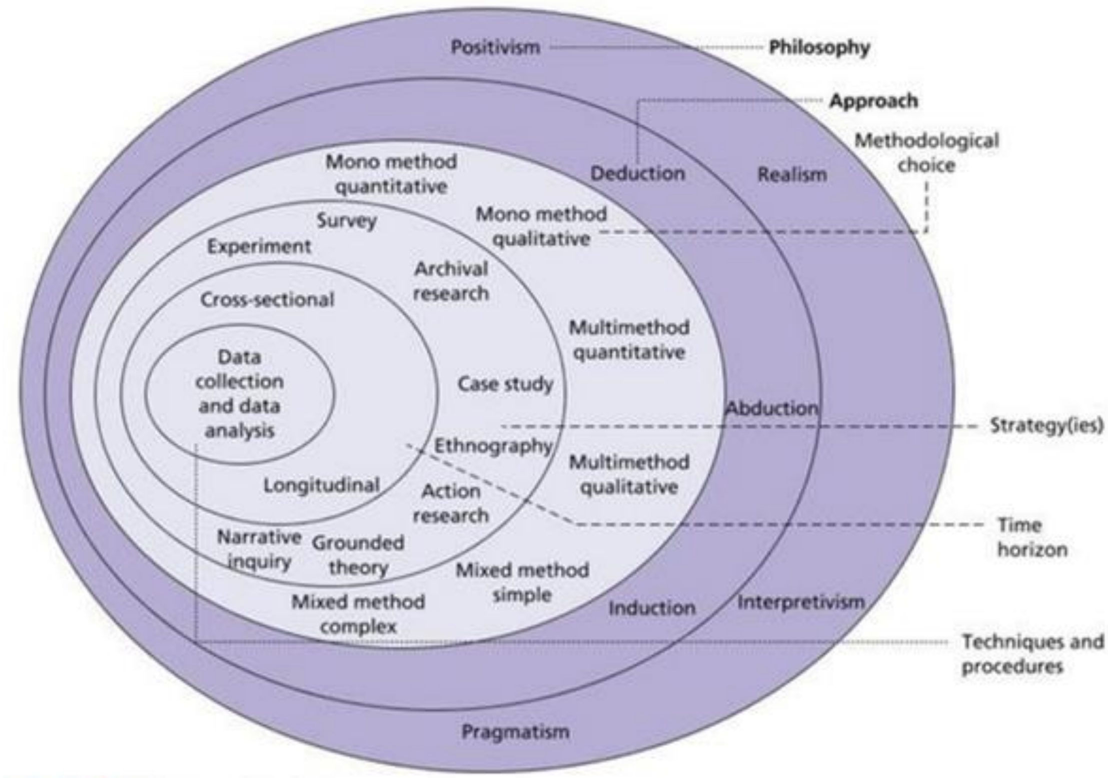


Figure 4-2: The Research Onion model (Saunders et al., 2012)

4.3. Research Philosophy

Deciding on the philosophy behind the research is the first layer of the Research Onion and is vital to the design of a feasible research methodology. The research philosophy reflects important assumptions about how the researcher sees the world. Easterby-Smith et al. (2012) highlight three important issues in research, which are: the philosophy that informs the research design; the choice of the method of inquiry that best serves the research conditions, and the researcher's ability to recognise which designs will work.

According to Renmenyi (1998), the researcher must consider their research perspective and the epistemological, ethical and ontological assumptions that will influence and support the strategy and methods selected for their research. Guba and Lincoln (1994) describe the fundamental concepts of research philosophy as epistemology, ontology and axiology (see Table 4-2). Two of these three philosophical concepts are fundamental to choosing a research philosophy: epistemology – which asks how we come to understand phenomena, and ontology - which asks what the phenomena are, what exists and what is the nature of an entity? Ontology concerns itself with what is true; epistemology concerns itself with how we know it is true. Ontology is about the nature of reality and epistemology is about "how knowledge can be created, acquired and communicated, in other words what it means to know" (Scotland, 2012).

Table 4-2: The assumptions of research philosophy (Sexton, 2003)

Epistemology (The how?)	General set of our presuppositions about how we absorb and come to accept what we know about our surroundings
Ontology (The what?)	Assumptions that we make about what constitutes reality
Axiology (The why?)	Presuppositions about the nature of values and the foundation of value judgments

4.3.1. Epistemology

Two fundamental approaches are used to describe how we acquire and make sense of knowledge about the world: "positivism" and "social constructionism (interpretivism)" (Easterby-Smith et al., 2012) (see Table 4-3). Positivist philosophy is informed by the view that the world conforms to fixed laws of causation as practiced in the natural and physical sciences. Positivist researchers argue that "the world exists externally and that its properties should be measured through objective measures rather than being inferred subjectively through sensation, reflection or intuition. They use the deductive approach for the research" (Easterby-Smith et al., 2012).

Interpretivisim is a subdivision of epistemology which “is directed at understanding phenomena from the individual’s perspective, investigating interaction among individuals as well as the historical and cultural contexts which people inhabit” (Creswell, 2009; Scotland, 2012). In contrast to positivism, interpretivisim relies on the researcher’s reflection and intuition to aid understanding and explores “the subjective meanings motivating the actions of social actors” (Saunders et al., 2009). Saunders et al. (2009) argue that an interpretivist perspective is particularly suited to business and management research, especially where interpretations of organisational behaviour and marketing and human resource management is involved. Because this study is investigating organisational behaviour and internalised beliefs, attitudes and behaviours, specifically attitudes to mobile computing technology, conservative management attitudes and changes to ingrained work practices and attitudes, interpretivisim or “social constructionism” is the most appropriate epistemological philosophy.

Table 4-3: Contrasting implications of positivism and social constructionism (Easterby-Smith et al., 2012)

	Positivism	**Social Constructionism**
The observer	Must be independent	Is part of what is being observed
Human Interest	Should be irrelevant	Are the main drivers of the science
Explanations	Must demonstrate causality	Aim to increase general understanding of the situation
Research progress Through	Hypotheses and deduction	Gathering rich data from which ideas are induced
Concepts	Need to be operationalised so that they can be measured	Should incorporate stakeholder perspectives
Units of analysis	Should be reduced to the simplest terms	May include the complexity of ‘whole’ situation
Generalisation	Statistical probability	Theoretical abstraction

through		
Sampling requires	Large numbers selected randomly	Small numbers of cases chosen for specific reasons

This study requires the researcher to become part of the construction environment; an immersive approach is taken in which the researcher familiarises himself with the daily routines and, more importantly, the attitudes and feelings held by different personnel to build a deep understanding of the construction environment. One of the goals of this study is to analyse the combination of physical and attitudinal conditions, which would either disrupt or contribute to the success of mobile computing. Many of these contributory factors are based on the social characteristics (psychological or behavioural) of the construction personnel who would use the technology. To develop the necessary empathetic understanding of on-site construction conditions and obtain insight into how the process of exchanging information operates, the researcher immersed himself into the situational context to gain knowledge using a combination of observation, reasoning skills and insight.

4.3.2. Ontology

Ontology, concerns itself with what is true; it is about the nature of reality. There are two approaches to classifying knowledge. The nomothetic approach is informed by the observation that society behaves according to general rules and therefore general laws can be applied to explain objective phenomena. The ideographic approach is informed by the observation that individuals are unique and therefore ascribes meaning according to subjective phenomena (Gill and Johnson, 2010). According to Burrel and Morgan (1979, as quoted by Gill and Johnson, 2010), nomothetic (realist) methodologies emphasise the importance of the rigorous use of systematic techniques in management research, focusing on testing hypotheses. In contrast, ideographic methodologies (idealism) emphasise the analysis of subjective accounts through immersion, placing the researcher in and among the observed without disrupting them (Burrel and Morgan, 1979 as quoted by Gill and Johnson, 2010). This latter approach is the one adopted for this research.

Table 4-4: A comparison of nomothetic (realism) and ideographic (idealism) methodologies (Gill and Johnson, 2002)

	Nomothetic	Ideographic
1	Deductive testing of theory	Inductive development of theory
2	Explanation via analysis of causal relationships and explanation by covering-laws	Access to subjective meaning systems and explanation of behaviour through understanding
3	Generation and use of quantitative data	Generation and use of qualitative data
4	Use of various controls, physical or statistical, so as to allow the rigorous testing of hypothesis	Commitment to research in everyday settings, while minimising the disruption caused the research to those being investigated so as to preserve the natural context in which their behaviour arises
5	Highly structured research methodologies to ensure replicability of above 1,2,3 and 4	Minimise structure to ensure above 2,3 and 4 (and partially as a result of 1)

4.3.3. Axiology

Axiology is the third aspect of philosophy that "studies judgements about value" (Saunders et al., 2009). At either end of its spectrum, it has two aspects 'value free' and 'value laden'. In value free research, the choice of what to study and how to study it is determined by objective criteria and in value laden research the choice is determined by human beliefs and experiences (Easterby-Smith et al., 2012). The chosen philosophical approach reflects the researcher's values. Given that this research takes the interpretivisim stand for the epistemological philosophy and the idealism position for the ontological philosophy, this means that the axiological philosophy falls within the value laden stance (see Figure 4-3). The value laden aspects of this research relate to judgments about the efficacy and benefit of collaborative and instructional management styles in a Saudi context into which mobile computers have been introduced.

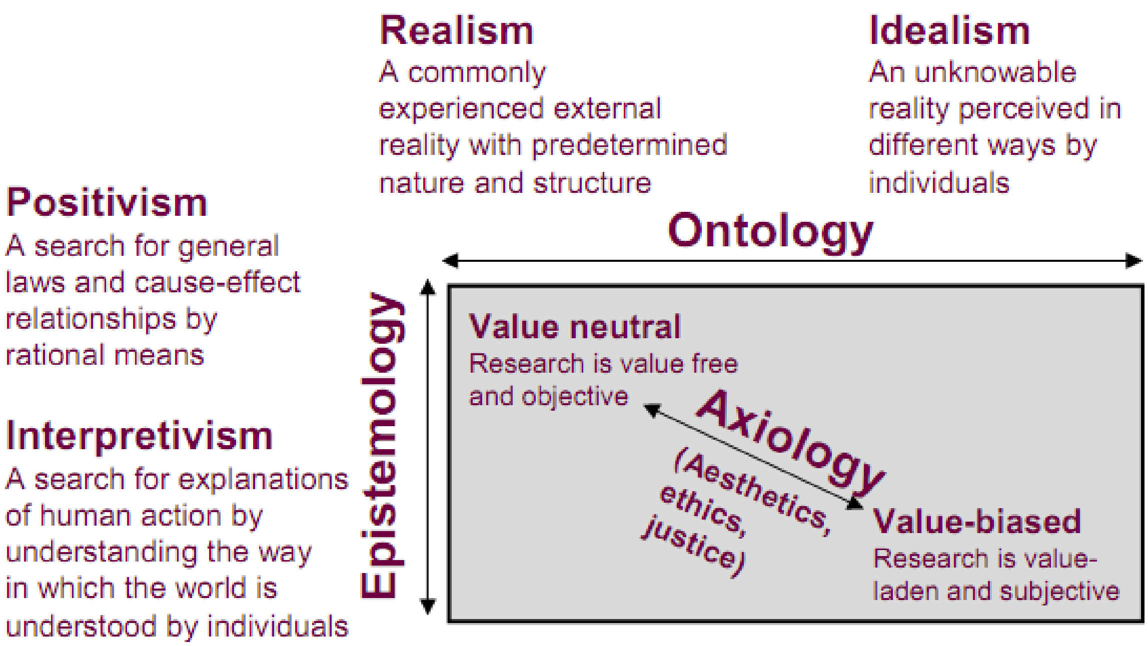


Figure 4-3: The research philosophy (Sexton, 2003)

4.4. Research Approach

Two fundamental approaches are used in empirical studies to derive a theory, which makes the data comprehensible: deductive and inductive reasoning. These are the two methods of reasoning which balance the use of logic and observation in the construction of social theories; this research combines the two approaches which have been defined by Saunders (2009), as abductive. Generally speaking, deductive reasoning works from the more general to the more specific while inductive reasoning works from the particular to the general; the abductive approach moves between the two.

To further elaborate on this, deductive reasoning methods move from cause to effect; inductive reasoning moves from effect to cause. Deductive reasoning emphasises the certainty of conclusions; inductive reasoning favours causation linked to probability. Inductive reasoning is more open-ended and exploratory, especially at the outset. It begins with specific observations, then detects patterns and forms tentative hypotheses that can be explored and developed into general conclusions or theories (Saunders, 2009).

In an inductive approach, a researcher sets the foundations by collating relevant data for their study. When sufficient data have been recorded, the researcher will step back to obtain a dispassionate perspective. At this point, the researcher is looking for patterns in the data, to deduce and build general laws that can make sense of such patterns. Thus, an inductive approach commences with a set of observations and proceeds from the particular experience of the individual to a more general set of propositions about such experiences. In other words, they move from data to theory or from the specific to the general (Creswell, 2005).

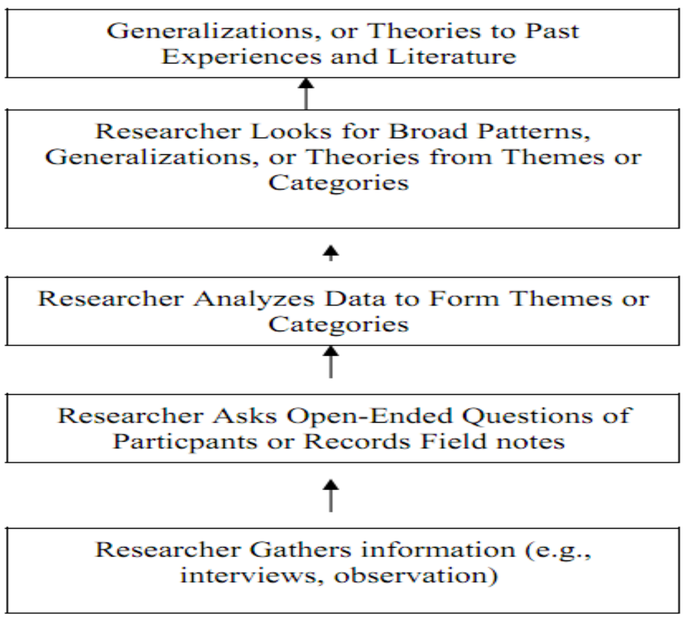


Figure 4-4: The inductive logic of research (Creswell, 2003)

The deductive approach traditionally implies an inquiry into an identified problem based on the testing of a theory. It thus goes from the theory to its empirical investigation. That is to say, it is a theory testing process which commences with an established law or proposition, and sets out to establish whether this proposition applies to specific instances. The inductive approach, by contrast, is an inquiry to understand a social or human problem from multiple perspectives (Yin, 2003).

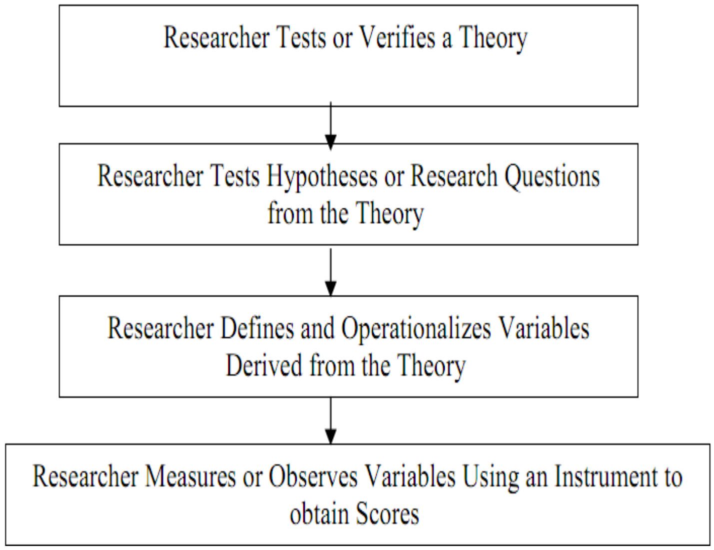


Figure 4-5: The deductive approach (Creswell, 2003)

In the process of conducting real research, it is difficult to separate the inductive and deductive approaches, as both are present to a greater or lesser extent. Indeed, this summary supports the view that "it is impossible to go theory-free into any study" (Richards, 1993). Saunders et al. (2009) agree that a combination of research methods is a useful means of achieving specific research objectives, arguing that, subject to the nature of the research topic, deduction and induction may easily be combined within a single research project; indeed, that there are benefits to combining them.

This research emphasises the need to improve communication practices between the project team members in order to enhance the delivery of construction projects. This is achieved by exploring the literature discussing the substitution of traditional communication tools for advanced mobile technology. The absence of established theories on the models, forms, advantages and disadvantages of the use of digital technology on-site, the sparse literature on how to implement a mobile computing system, the need for the researcher to immerse himself in the construction context, the move from the particular context of a single large construction project to the general

Saudi construction context and the uncertainty regarding cause and effect all suggest that an abductive research approach is best suited for this research.

4.5. Research Choices

This section refers to the appropriate selection of the research method to be adopted to gather data. Figure 4-6 represents Saunders et al.'s (2009) presentation of research methods as a choice between the multiple method or the mono method. The latter uses a single data collection technique and corresponding analysis procedures. The multiple method approach uses more than one data collection technique and analysis procedure to address the research question. Tashakkori and Teddlie (2003) argue that multiple methods are helpful because they contribute more comprehensively to answering the research question, and offer the researcher a broader and more nuanced basis for evaluating whether the research findings and inferences drawn from them can be trusted. In summary, this research chooses multiple methods to address the research questions because they give a wider picture.

Multiple methods can be divided into two categories, which are mixed and multi methods. The idea underlying the multi method approach is to use either a qualitative or quantitative data collection method and analysis, and more than one data collection technique (Tashakkori & Teddlie, 2003). For example, a researcher might use both questionnaires and structured observation (multi-method quantitative study) or interviews and diary (multi-method qualitative study). In other words, multi-method does not combine quantitative and qualitative data collection and analysis techniques, whereas mixed method combines quantitative and qualitative approaches.

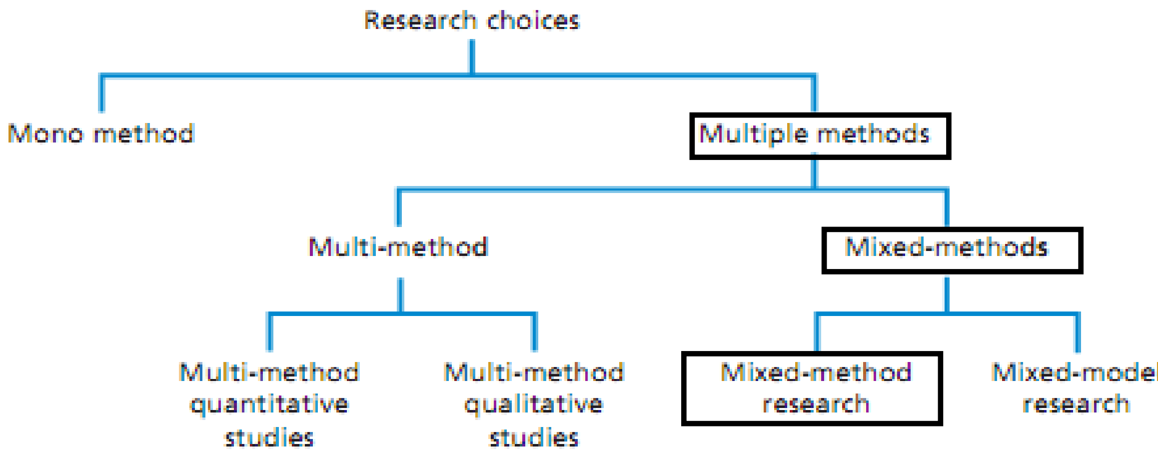


Figure 4-6: Research choices (Saunders et al., 2009)

A mixed method was chosen to address the research questions for this study, in order to provide a more balanced picture; in addition, mixed methods improve trust and reinforce inferences drawn from the research (Tashakkori & Teddlie, 2003). Quantitative research is useful in filling the gaps of a qualitative study. “It may be that not all issues are suitably addressed through a solely quantitative or qualitative investigation” (Blaxter et al., 2006). The mixed method is made up of two categories, mixed method research and mixed model research. The latter uses quantitative and qualitative collection techniques, but analyses the data either quantitatively or qualitatively. This research uses mixed method research, where quantitative and qualitative data collection methods are utilised and analysed independently.

Quantitative research added to the study’s generalisability, helped the formulation of the interview themes and helped guard against bias. The researcher attempted to avoid bias by taking technical and strategic measures to demonstrate an anti-bias approach. The study’s inbuilt strategic safeguard against bias is the balancing of interviews with a quantitative questionnaire to attain a degree of objectivity. The differences between quantitative and qualitative methods and their respective strengths and weaknesses are presented in Table 4-5 and Table 4-6 respectively.

Table 4-5: The differences between quantitative and qualitative research. (Bryman, 1998 as quoted by Naoum, 2007)

	Quantitative	**Qualitative**
1. **Role**	Fact-finding based on evidence or records	Attitude measurement based on opinions, views and perceptions measurement
2. **Relationship between researcher and subject**	Distant	Close
3. **Scope of findings**	Nomothetic	Idiographic
4. **Relationship between theory/concepts and research**	Testing/confirmation	Emergent/development
5. **Nature of data**	Hard and reliable	Rich and deep

While quantitative research may be described as 'objective' in nature, qualitative research is characterised as 'subjective' (Naoum, 2007). The quantitative method is associated with a deductive approach and the qualitative method is related to an inductive approach (Creswell, 2003). The fundamental distinction between the two methods is set out below (Marczyk et al., 2005):

- Quantitative research involves studies that make use of statistical analyses to obtain findings. Key features include formal and systematic measurement and the use of statistics.
- Qualitative research involves studies that do not attempt to quantify their results through statistical summary or analysis. Qualitative studies typically involve interviews and observations without formal measurement.

A mix of both these methods is used in this research, with the primary focus being on qualitative data, as this was deemed best suited to a thorough understanding of the Saudi construction environment.

Table 4-6: Strengths and Weaknesses of Quantitative and Qualitative Research (Easterby-Smith et al., 2012)

	Quantitative	Qualitative
Strengths	• Can provide wide coverage of a range of situations. • Can be fast and economical. • Where statistics are aggregated from large samples, may be of considerable relevance to policy decisions.	• Data gathering methods seen as more natural rather than artificial. • Ability to look at change process over time. • Ability to understand people's meaning. • Ability to adjust to new issues and ideas as they emerge. • Contributes to theory generation.
Weaknesses	• The methods used tend to be rather inflexible and artificial. • They are not very effective in understanding processes or the significance that people attach to actions. • They are not very helpful in generating theories.	• Data collection can be tedious and require more resources. • Analysis and interpretation of data may be more difficult. • Harder to control the pace, progress and end-points of research process. • Policy-makers may give low credibility to results from qualitative approach.

4.6. Research Strategy

According to Naoum (2007), research strategy is defined as the way in which the research objectives can be questioned. This is the fourth level of the Research Onion. Choosing the appropriate strategy for this research was difficult because the research strategy must address the research questions and objectives within the timeframe set as well as be true to the research's philosophical assumption. This research's is aim to develop a framework strategy to improve the management practice of construction projects, in particular the provision and sharing of information for site based workers using mobile computing. The study is essentially about linking an information system and mobile technology with project management to solve the problem of communication by enhancing the mobility of site based personnel with better information flow and fast and accurate decision-making. The data collection strategy for this research relied primarily on case studies and, secondly, on surveys.

4.6.1. Case studies

Saunders et al. (2009) indicate that the case study strategy is the polar opposite of the experimental strategy and also differs significantly from the restricted research context of the survey with its limited capacity to explore and understand. “The case study is the method of choice when the phenomenon under study is not readily distinguishable from its context” (Yin 2003 as quoted by Blaxter et al., 2006). Naoum (2007) writes that case studies are used to achieve in-depth analyses of people or organisations. As the case study intrinsically focuses on a particular context of a problem, the conclusions drawn may not support universal generalisation. There are three types of case study designs (Naoum, 2007):

- The descriptive case study which is similar to the concept of the descriptive survey (i.e. counting), except that it is applied to a detailed case.
- The analytical case study which is similar to the concept of the analytical survey (i.e. counting, association and relationship), except that it is applied to a detailed case.
- The explanatory case study which is the theoretical approach to the problem. It explains causality and tries to show linkages among the objects of the study. It asks why things happen the way they do. It also suggests that a single cause can have a specific effect. In other words, the researcher collects facts and studies the relationship of one set of facts to another with the hope of finding some causal relationship between them.

The case study strategy was supplemented by the interview method to collect data for this research as this allowed the researcher to dig deeper. Saunders et al. (2009) explain the suitability of case studies based on their capacity to generate answers to the ‘why?’ as well as the ‘what?’ and ‘how?’ questions. For this reason, the case study strategy is most often used in explanatory and exploratory research. The advantages and disadvantages of case studies are highlighted below (Blaxter et al., 2006):

4.6.1.1. Advantages

1. Case study data drawn from people’s experience and practice has authenticity because it is based on their reality.
2. Case studies allow for generalisations from a specific instance to a more general issue.
3. Case studies allow the researcher to illustrate the complexity of social life. Good case studies build on this complexity to explore alternative meanings and interpretations.
4. Case studies can provide a data source from which further analysis can be made. They can, therefore, be archived for further research work.
5. Because case studies build on actual practices and experiences, they can be linked to action and their insights contribute to changing practice.
6. Because the data contained in case studies are close to people’s experiences, they can be persuasive and accessible.

4.6.1.2. Disadvantages

1. The very complexity of a case can make analysis difficult.
2. While the contextualisation of aspects of the case strengthen this form of research, it is difficult to know where ‘context’ begins and ends.

4.6.2. Survey strategy

Saunders et al. (2009) state that surveys are usually associated with the deductive approach. Surveys are commonly used in business and management research and are most frequently used to answer questions concerning who, what, where, how much and how many. Surveys, therefore, tend to be used for exploratory and descriptive research.

Marczyk et al. (2005) explain that survey studies involve asking large numbers of people questions about their behaviours, attitudes, and opinions. Some surveys merely describe what people say they think and do.

Other survey studies attempt to establish relationships between the characteristics of the respondents and their reported behaviours and opinions. Fellows and Liu (2008) describe how surveys operate on the basis of statistical sampling and only extremely rarely are full population surveys possible, practical or desirable. Despite the fact that the survey methodology does have some disadvantages, which Fellows and Liu (2008) talk about, the researcher felt that it would be a suitable secondary method for collecting data for this particular research as the disadvantages can be mitigated. The advantages and disadvantages of the survey method are highlighted below (Blaxter et al., 2006):

4.6.2.1. Advantages

1. With an appropriate sample, surveys may aim at representation and provide generaliseable results.

2. Surveys can be relatively easy to administer and need not require any field-work.

3. Surveys may be repeated in the future or in different settings to allow comparisons to be made.

4. With a good response rate, surveys can provide a great deal of data relatively quickly.

4.6.2.2. Disadvantages

1. The data, in the form of tables, pie charts and statistics, become the primary focus of the research report, with a loss of linkage to wider theories and issues.

2. The data provide snapshots of points in time rather than a focus on the underlying processes and changes.

3. The researcher is often not in a position to check first-hand that respondents have a clear understanding of the questions asked. Issues of truthfulness and accuracy are thereby raised.

4. The survey relies on breadth rather than depth for its validity. This is a crucial issue for small-scale researchers.

4.7. Time Horizons

In this PhD research, the researcher has sought to describe the incidence of a phenomenon which is the timely information exchange by a project team within an organisation, the IT tools that they are using and the information flow at a particular point in time. Saunders et al. (2009) explain that the cross-sectional in time horizon is a snapshot while a diary is an example of a longitudinal study. This study is cross-sectional in that it is a study of a particular phenomenon at a given point in time and enough data can be obtained to make generalisations given that it is not possible to access all firms for a longitudinal study. Saunders et al. (2009) acknowledge the fact that most research projects undertaken for academic courses are necessarily time constrained.

4.8. Data Collection Methods

Table 1-2 in Chapter 1 illustrates the research process that consists of the following stages: the literature review, case studies, the survey, and a focus group. The case study data collection methods include interviews and observations. In order to answer the research questions, a case study approach is adopted to identify the communication methods used and the obstacles encountered by the management of Saudi construction firms. After discussing the results, a focus group was used to develop an Interpretive Structural Modelling (ISM) to map the challenges that affected the implementation of mobile computing. A strategic model was developed which would meet site workers' needs.

4.8.1. Literature Review

The review of the literature was a valuable source of knowledge on the historical development of IT, both from a technical and an attitudinal viewpoint. The literature materials consulted included academic journal papers, industrial reports, technical specifications and books. The most relevant era in terms of improved design and increased capability of mobile computing (Chapter 3, Section 3.2) was the decade leading up to 2015. This decade is discussed in the literature (Chapter 3, Section 3.5) in terms of its development potential rather than in terms of its achievement. After all, smart-phone is still in its infancy (Chapter 3, Section 3.3). Considering the needs of large contractor companies to enhance their communication lines utilising traditional tools (Chapter 3, Section 3.4 and Chapter 2, Section 2.4) between the construction site and the site office, recent literature focuses less on individual applications of IT in construction that supports two or a few types of information, and more on the potential (Chapter 3, Section 3.5.3) for uniting them in a cohesive overall system through integration, using BIM or information systems.

4.8.2. The Questionnaire Method

This research used the questionnaire as a secondary means of data collection to ensure generality of the results. The survey investigated the types of information on-site staff exchange and the communication methods that they use. It also identified the opinions of the participants, their satisfaction with the methods they use and the extent of their on-site collaboration. The survey also identified perceived challenges to the implementation of mobile computing within the construction industry and recommended the type of mobile devices to be used for on-site construction communication.

4.8.2.1. Questionnaire Design

The questionnaire incorporated rating questions, which are “often used to collect opinion data” (Saunders et al., 2009). Rating questions comprise a five-point Likert scale which rates attitudes and opinions, that is evaluates the issues in question based on how well they discriminate between high and low scoring responses. The response options range from "Extremely good" to "Not good at all" and from "Very important" to "Not important at all" and from “Most used” to “Not used at all”. The five agreement points on the rating scale allow respondents to tick the middle ‘neutral’ option, a more attractive option for respondents than the requirement to state that they ‘do not know’. By using this type of scale it became easy for the researcher to determine and assess the impact of themes identified from the literature.

Used in isolation, questionnaires have certain weaknesses which are set out below. The weaknesses inherent in questionnaires have been balanced out by the secondary auxiliary role contributed by the quantitative element in data collection. One of the weaknesses of questionnaires is that they involve a “superficial and sometimes too brief an engagement with the topic on the part of the respondent” (Fellows and Liu, 2008). The literature states that findings may be inconsistent from one response to another because participants are not always thorough in their responses” (Brinkmann, 2013). The interviewer is not on-site to challenge the tendency to present ourselves in a good light. Particularly where social or cultural judgments are required, some responses may contain a “perceived acceptable response, even if not true.” This tendency is known as “social desirability bias” (Hesse-Biber and Nagy, 2010, p.66). This research has attempted to account for this bias.

4.8.2.2. Questionnaire Layout

When planning the questionnaire, the researcher prepared straightforward and easy to understand questions. The questions progressed from ones asking for general information to ones which asked for more specific information. The researcher divided the questionnaire into five parts. The first part of the questionnaire contained general questions about the respondent's background, such as their particular field of study, their area of work and educational level, the answers to which would help the researcher contextualise the sample and link it to the research findings. The second section investigated perceptions concerning levels of collaboration and satisfaction and current communication tools used in construction projects. The third section presented a list of types of information which the on-site staff would like to exchange while on-site. The fourth section focused on the factors that may challenge the use of mobile computing within the construction industry. The final part presented the mobile devices that it was suggested be used for on-site construction communication.

4.8.2.3. Pilot Study

A pilot study was conducted using a small population sample of six well-informed respondents. The aim was to detect unclear or ambiguous questions and provide an early assessment of the quality of the questionnaire. A covering letter clarified the goal of the questionnaire and participants were asked to critically evaluate the questions and provide comments on their sufficiency, the time taken to complete the survey and any ideas for enhancement. The pilot questionnaire was submitted to ten construction professionals whose long established work records qualified them to test it. The six who responded provided ideas that improved the final form of the questionnaire. Their comments led the researcher to reduce the length of the questionnaire, making it quicker to complete and the clarity of some questions was improved by rephrasing.

4.8.2.4. Questionnaire Sample

The sample strategy used to recruit questionnaire respondents was the snowball sampling strategy. The snowball strategy uses a domino effect by enlisting the support of participants to inform and encourage others to participate in the recruitment process. This study relied upon a network of construction professionals to involve themselves in the recruitment process. The questionnaire was distributed to 350 potential participants. The end result was the completion of 205 self-administered questionnaires from a total submission of 350.

The questionnaire was delivered and collected by hand after completion (Delivery and Collection Questionnaires). The researcher opted to do this to “increase the research data reliability” (Saunders et al., 2009). This technique allows the researcher to interact with the respondents and maintain control. It also allows for the distribution and collection of the questionnaires in an orderly fashion. This method of collating quantitative data in social science surveys is favoured because it delivers a high rate of response, and ensures accurate sampling. However, for it to operate efficiently, the questionnaire must be self-explanatory to ensure high quality data (Oppenheim, 2000).

4.8.3. Case Studies

Case studies were the main research method used to investigate the key challenges in providing timely and relevant information to site based construction workers engaged in public sector construction projects within the Kingdom of Saudi Arabia and the existing communication technologies used in Saudi Arabia by the site based construction workforce while understanding the practical information requirements on construction-sites. The explanatory case study explains causality and tries to show linkages among the objects of the study (Naoum, 2007). Yin (2003) advocates the explanatory case study as a useful means of using evaluative language to explain presumed casual links in real-life investigations that are too nuanced for a quantitative survey.

For the case studies a mix of observation and interviews was used to explore the methods that construction personnel use to exchange and manage site information. The objective of the case studies were to understand the general circumstances on 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 steps discussed below.

4.8.3.1. Interview Method

The interview method involves questioning, probing, listening and observing to achieve trust and engage with an interviewee (Blaxter et al., 2006). Qualitative interviews take an exploratory approach to investigate the subjective interpretations of social phenomena such as the communication patterns, the methods used to record and pass information on construction-sites. Interviews may be formalised and structured or the questions may be informal and unstructured conversations (Saunders et al., 2009). Between these positions, lie semi-structured interviews. Saunders et al. (2009) advise researchers carrying out semi-structured interviews to have a prepared, thematically relevant list of questions at hand. Also, to ensure that they respond to the interviewee's tone and body language, maintain the conversational flow, vary the order of questions if necessary and allow for supplementary questions to clarify uncertainties or expand on themes that arise in the course of discussion.

Asking about a specific experience is preferable to asking in general terms about a topic. Saunders et al. (2009) remind us that an interpretivist epistemology lends itself to an empathetic interpretation of the meanings that participants ascribe to various phenomena and involves collaboration between the researcher and interviewee to build an understanding based on mutuality, respect and observation of body language and tone of voice. In this sense, interviews involve "collecting data through watching or engaging in activities" (Blaxter et al., 2006). The appeal of loosely structured interviews is that more complex topics can be investigated and replies can be clarified. A more empathetic research atmosphere may produce a deeper more forthcoming response (Fellows and Liu, 2003). A good interviewer will ask supplementary questions so that the interview becomes more like an informal conversation and much less like an interrogation with set questions and responses. The disadvantages of loosely structured interviews are that inchoate data can be time consuming to collect and difficult to analyse and that interviewer bias must be countered.

The interview questions aimed to build an understanding of current management practice. This was achieved gradually through blending layers of individual experience and anecdote rather than through eliciting a flat explanation of management practices. A clear link was found between managers in different roles and the reasons they favoured particular communication tools and techniques over others. The interviews concluded with a discussion of the problems the individuals encountered and the difficulties they anticipated when using a hand held device on-site. In the course of the interviews, the greater the involvement and participation of the interviewees, the greater the interviewer's "understanding of the reasons for their decisions, their attitudes and opinions" (Saunders et al., 2009). The semi-structured interview was divided into four sections:

- The construction communication.
- The key information requirements and the communication processes.
- Mobile computing technology.
- The key challenges that affect the implementation of mobile computing.

4.8.3.2. Interview Sample

The sampling strategy is the method used to choose suitable interviewees from the population of interest to obtain reliable data. After the semi-structured interview was designed and pilot tested, a purposive sampling strategy was chosen. It is neither possible nor necessary to collect data from the entire population of a community to arrive at valid findings. In qualitative research, a sample or a subset of a population is deemed sufficient to reliably reflect the thoughts and opinions of the wider population. Because the background experience and inherent quality of a purposive sample is fundamental to the quality of data obtained, the reliability and competence of the interviewee is fundamental to the success of the research (Tongco, 2007).

Although it is recognised that randomisation reduces bias and allows for the extension of results to the entire sampling population (Brinkmann, 2013), it was not possible in this case to use random or probability sampling to select either the interview or the questionnaire participants. Mobile computing is not sufficiently widely embedded in Saudi construction to make random sampling a viable choice. However, according to the literature, purposive sampling is also effective in conditions which closely match this study of a nascent commercial and/or cultural domain (in this case the emerging use of mobile computing on construction-sites) and about which knowledgeable experts either have experience or are well informed (in this case experienced construction professionals).

The researcher held discussions with senior figures in construction companies and used observation and his construction contacts to exercise his judgment on the reliability and competency of potential interviewees because “it is critical to be certain of the knowledge and skill of the informant, as inappropriate informants will render the data meaningless and invalid” (Godambe, 1982, quoted in Tongco, 2007). The researcher used what the literature describes as “key informants”, that is observant and reflective members of the construction community who are well informed about the business culture and are both able and willing to share their knowledge (Tongco, 2007). General discussion before and during interviews assured the researcher that his information satisfied the reliability test in that it was consistent across the community (Tongco, 2007). The researcher must also be alert for possible biases on the part of the interviewees.

The sampling strategy is the method used to choose suitable elements (people and organisations) from the population of interest for the research to obtain suitable data. After the semi-structured interview was designed it was pilot tested with three respondents from the target population to ensure that it was easy to complete and the questions easily understood. For both interviews and questionnaire, the participants were recruited from within large and complex contractor companies classified by the relevant Saudi Agency (Ministry of Municipal and Rural Affairs) in the first or second category for buildings and roads (MACC, 2013). Three large construction projects were used as case studies. The number of interviewees per construction project depended on the Organisational Breakdown Structure of the contractor firm. Target populations are site-based workers engaged in public sector work. The researcher targeted project managers, site supervisors and site engineers who are responsible for a group of eight workers at least.

4.8.4. Focus Group

The aim of this research was to develop a strategy to improve how information is supported and managed by site based workers. The strategy was evaluated by construction professionals. Therefore, the focus group was used to validate the proposed strategy for a construction project in Saudi Arabia.

4.9. Data Analysis

After primary and secondary data was collected, the data was analysed to determine various themes and theories about communication and relationships on-site. The preparation and testing of the questions made the transformation of transcripts of data into relevant thematic analysis easier. The analysis phase is made up of several key stages which aim to build an understanding of the information requirement, the current practices and other associated issues which are essential to developing the strategy. Figure 4-7 presents the road map for the research stages.

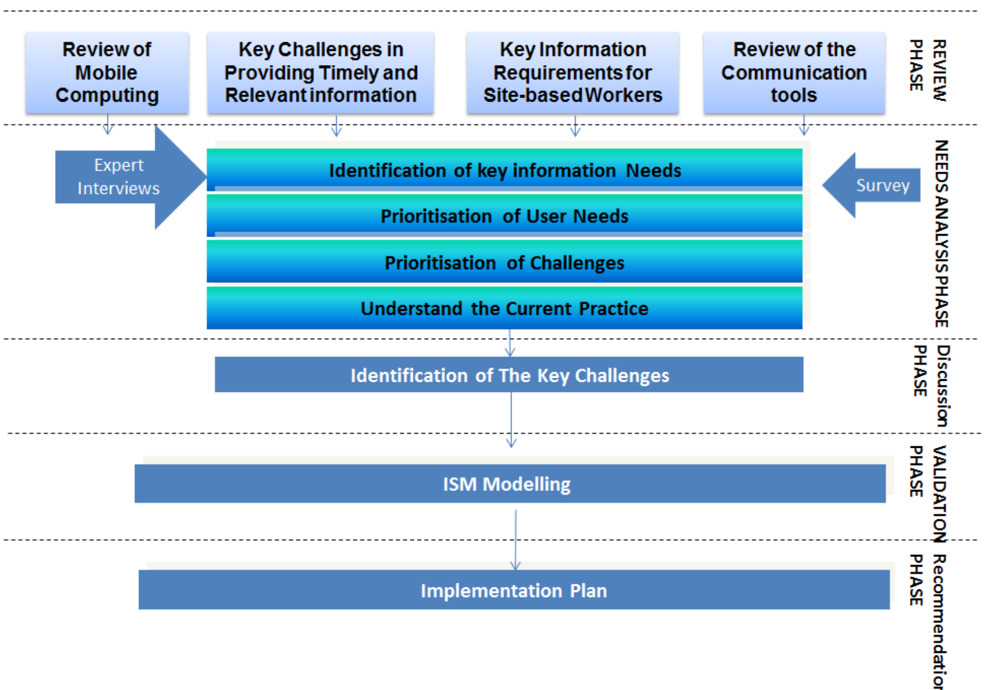


Figure 4-7: The key steps in the research processes.

This phase was concerned with the processing of data from the interviews and questionnaires into useful and reliable information in order to meet the research objectives and answer the research questions. As this research adopted mixed methods for data collection, different techniques were used in the data analysis. Table 4-7 displays the differences between quantitative and qualitative data.

Table 4-7: The Differences between Quantitative and Qualitative data (Hair et al., 2007)

Quantitative data	Qualitative data
• Based on meaning derived from members. • Collection results in numerical and standardised data. • Analysis conducted through the use of diagrams and statistics	• Based on meanings expressed through words. • Collection results in non-standardised data requiring classification into categories. • Analysis conducted through the use of conceptualisation

Researchers should always use the methods of inquiry that best serve the conditions and the nature of the study. Mobile computing is an emerging and largely untried phenomenon particularly in the Saudi context. A qualitative and inductive approach was valid because, as has been seen, they are both suited to exploratory studies which concentrate on discovery and understanding of new phenomena. As highlighted in Section 4.5, the mixed method approach used in this study privileges qualitative methods, with the quantitative element playing a secondary auxiliary role, ensuring that “all relevant voices are heard” (Howe, 2004, p.54) to obtain “deeper, more genuine expressions of beliefs and values to foster a more accurate description of views held” (Hesse-Biber and Nagy, 2010, p.64).

The awareness that interviewing relies on subjectivity makes it possible to use a quantitative questionnaire to counter this subjectivity and balance notions of detachment and involvement, of fact and opinion and objectivity and subjectivity (Brinkmann, 2013). Generalisability is about the extent to which findings in one context can be transferred to other contexts. However, the use of a questionnaire, observation at construction-sites and feedback from interviewees informed analytic probabilities, which could be, applied to Saudi construction sites in general.

This qualitative study uses an auxiliary quantitative questionnaire to enhance the generalisability of a qualitative study. A quantitative study provides an opportunity to confirm the reliability of qualitative findings by examining the extent to which research findings from similar questions yield similar responses. Where responses differ, a quantitative study provides the option for exploring contradictory results. Findings from a qualitative study can be tested using a quantitative questionnaire method to confirm that the qualitative findings are applicable to a larger quantitative sample, allowing the researcher to generalise qualitative results to a wider population (Hesse-Biber and Nagy, 2010, p.66).

In research studies, data analysis includes some steps such as preparing the data for analysis, analysing the data and interpreting the data. Preparing data includes checking and entering the data into a database and transforming the data. When preparing the qualitative data for this study, the researcher transcribed the responses given verbatim and then translated the data from audio-recorded interviews from Arabic to English. Following this, the findings from each case study and the organisational documents and observation notes pertaining to that study were analysed using content and thematic analysis.

Content analysis is a simple method of analysing interview data that turns textual data into content categories for open-ended questions, which helps to summarise the answers. Thematic analysis is a qualitative analysis method for "identifying, analysing and reporting (themes) within data for open-ended questions. It minimally organises and describes your data set in (rich) detail" (Braun & Clarke, 2006: 79). It is a systematic approach that emphasises identifying patterns of meaning in a dataset. To analyse the quantitative data, the researcher prepared and entered the questionnaires into the computer software SPSS to code it, keeping in mind the; (Saunders et al, 2009)

- type of data (scale of measurement);
- format in which the data will be inputted into the analysis software;
- impact of data coding on subsequent analyses (for different data types);
- need to weigh cases; and
- methods which will be used to check data for errors (Saunders et al., 2009).

4.10. Summary

The chapter gave a detailed description of the research process undertaken for this study and described the methodology used in Section 4.2, which provided details of the research design and the choice of research models. It outlined the philosophical assumptions underlying the research, justifying the interpretivist approach, which was underwritten by the use of mixed methods. A critical assessment of the advantages and disadvantages of each method was given and the method chosen was justified in Section 4.6. This study is qualitative and uses an auxiliary quantitative questionnaire to enhance the generalisability of the study. The use of a questionnaire, observation at construction-sites and feedback from interviewees informed analytic probabilities, which could be applied to Saudi construction sites in general. Also, the questionnaire provides an opportunity to confirm the reliability of qualitative findings by examining the extent to which research findings for similar questions yield similar responses. Section 4.8 explains the research methods and justifies the design, distribution techniques, sample strategy, pilot tests, and so on. Moreover, this chapter will discuss the analysis stage of the research methods in the latter section. Following on from that, Chapters 5 and 6 will present the data that was collected.

Chapter 5: Quantitative Data Results

5.1. Chapter Overview

This chapter summarises the key findings from the research survey. The rationale for the survey was presented in Chapter 4 while the process of undertaking a quantitative study was described in Sections 4.5 and 4.8.2. This chapter presents the key stages of the research which helped develop a comprehensive understanding of the information required, the communication tools used at the time and relevant issues related to mobile computing usage in Saudi construction sites. Survey findings were later used in Chapter 7 to be discussed and guide the development of the strategy. The responses to the questionnaire, using descriptive statistics, and factor analysis, are presented and discussed in this section.

5.2. Reliability

Initially, the first step in analysing the questionnaire data was to test the questionnaire reliability. The collected data must be reliable and sufficient in order to be useful. The reliability can be tested using rating questions (Sections 5.3.3 and 5.3.4), which comprise of a five-point Likert scale rating attitudes and opinions, in order to evaluate the items in the question based on how well they discriminate between high and low scoring responses. The reliability of the Likert scale was tested using Cronbach's α coefficient (see Tables 5-1 and 5-2). According to Pallant (2001) the coefficient < 0.7 would be considered a reliable scale. Cronbach's α measures consistency in the answers across items within a scale, thus confirming that the scale used is a reliable one and that items within the scale measure for the same thing.

In this study the reliability was calculated for two scales: information requirements for on-site construction and challenges facing mobile computing in construction. The reliability for the information requirements (Section 5.3.3) was found to be 95% (0.95) and 93% (0.938) for the challenges (Section 5.3.4). This indicates that the scores of both scales were highly reliable and there is consistency of the scale with the sample size. Other studies such as Wu and Ding (2008), Narang (2011), Pajek et al. (2011) and Nourbakhsh et al. (2012) achieved 0.97, 0.96, 0.96, and 0.955 respectively.

Table 5-1: Reliability test score for information requirements (Section 5.3.3).

Reliability Statistics	
Cronbach's Alpha	N of Items
.957	29

Table 5-2: Challenges facing mobile computing (Section 5.3.4).

Reliability Statistics	
Cronbach's Alpha	N of Items
.938	23

5.3. Descriptive Analysis

Descriptive statistics describes the main features of the data using a numeric mode. Several types of tests are used in descriptive analysis, such as the percentage of specific answers, the mode and median for one item or a group of items, as well as the severity index (SI) to compute the items' rank according to their significance. The next section (and Appendix D) present the respondents' background information. The section below then offers a description of a few factors that relate to construction projects, the communication tools currently used in construction projects, the information requirements on site (at the point of work) and finally the challenges that effect the adoption of mobile computing technology on construction-sites.

5.3.1. Respondent Background

5.3.1.1. Area of Work

In the beginning, this question was asked to categorise the participants who returned the questionnaire according to their area of work. As presented in Table 1.1 (Appendix D) and Figure 5.1, just over two thirds - 68.8% of respondents - were found working in contractor firms; 18% were employed with the public sector and approximately 13% of the respondents were consultants. This question was required to filter the respondents' area of work as the target population for this study was participants working in contractor companies. Participants working in the public sector and consultant firms were excluded.

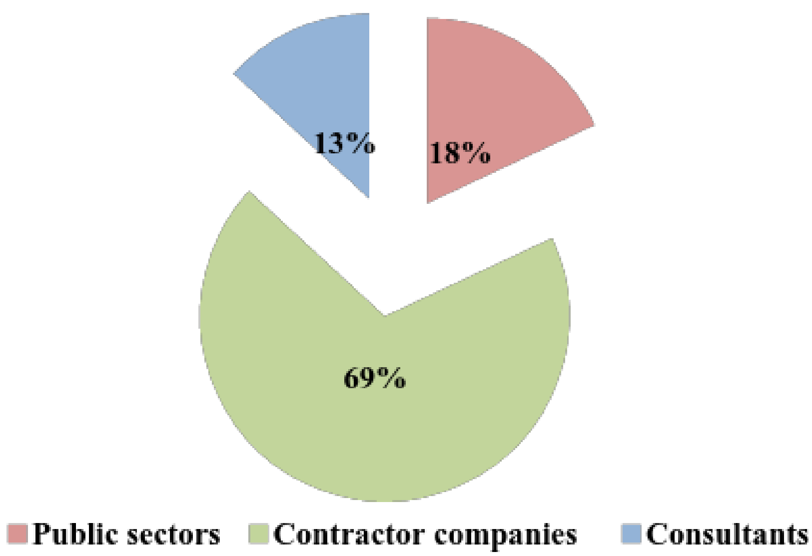


Figure 5-1: The percentages of answers of the area of work

5.3.1.2. The Original Field of Specialisation

Overall, the great majority of the participants originally specialised in engineering (almost 72% of the sample). This was followed by 14% of the sample who specialised in architecture while the remaining 11% specialised in management.

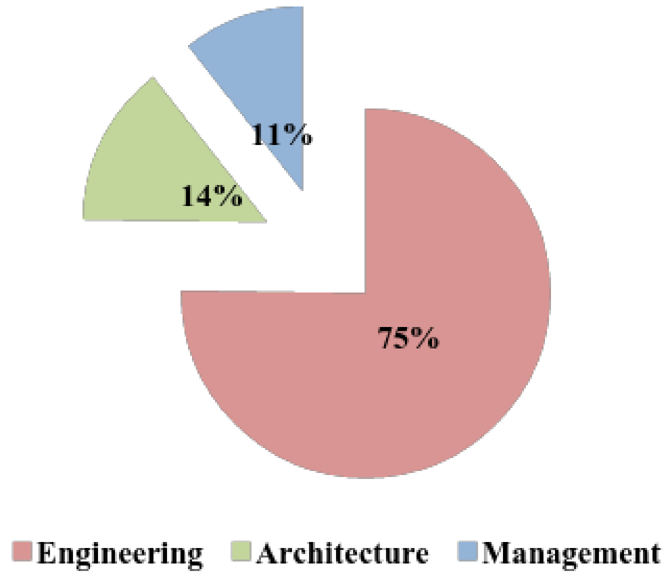


Figure 5-2: The percentages of answers on the original field of specialisation

5.3.1.3. The Highest Level of Education

When replies to the question regarding highest level of qualification were analysed the results showed that the majority of the participants held a Bachelor's degree (67% of the sample) while 13% had a qualification below a Bachelor's degree, 8% of the participants held a PhD while 6% held a Masters' degree.

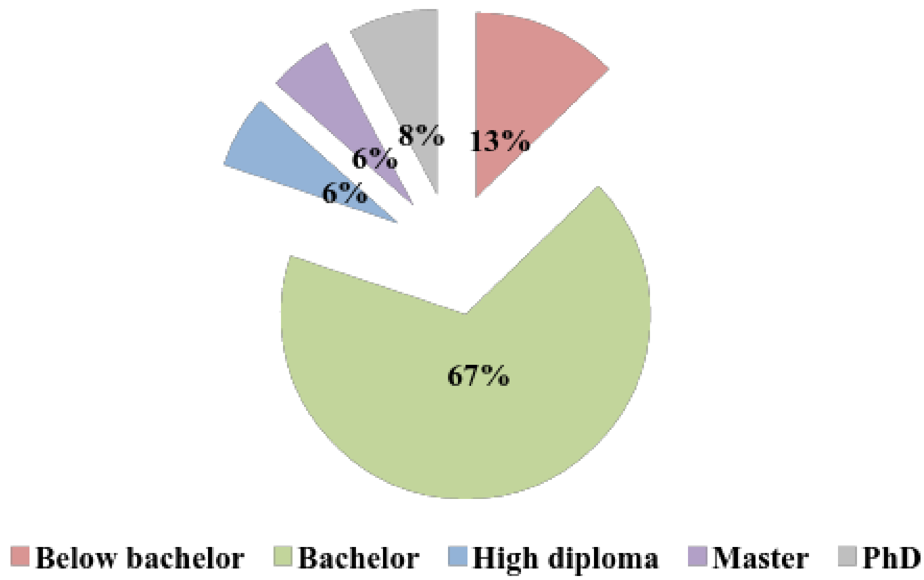


Figure 5-3: The percentages of answers regarding the level of education

5.3.2. Factors Related to Construction Sites

5.3.2.1. The Level of Inter-collaboration within Construction Projects

Participants were asked to rate, on a 5-point Likert scale, the extent of their inter-collaboration on construction projects. Their rating ranged from 1 = not good at all to 5 = extremely good. By choosing the mid-point, almost 38% rated collaboration as falling between 'good' and 'not good'. However, when the percentages above and below the neutral points was added up it was evident that most of the respondents feel that the level of collaboration is either 'good' or 'extremely good' (43% good; 11% extremely good). Only 8% stated that the collaboration is 'not good' while 1% stated that it was 'not good at all'. Therefore, on balance, there seems to be good inter-collaboration on construction projects.

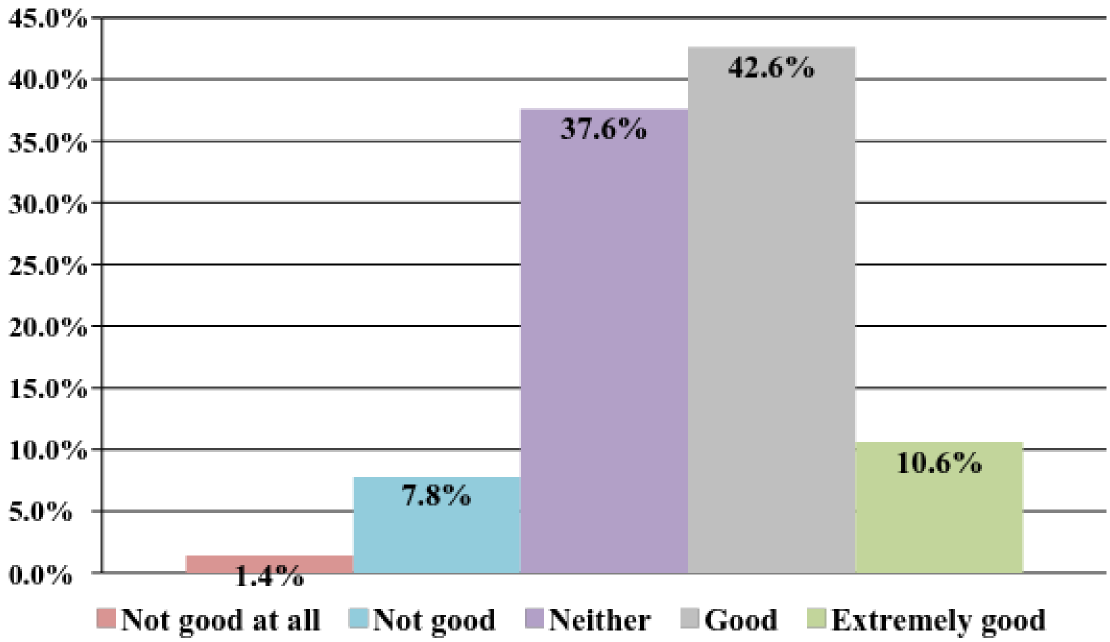


Figure 5-4: The frequency of answers describing collaboration levels

5.3.2.2. The Level of Satisfaction with Existing Communication Tools in Saudi Construction Sites

Participants were asked to rate their satisfaction with existing communication tools on Saudi construction-sites. Their rating was measured on a 5-point Likert scale, ranging from ‘not good at all’ to ‘extremely good’. The results show that the neutral point between ‘good’ and ‘not good’ was chosen by almost 40% of the respondents. When this response is removed from the equation, the remaining responses indicate satisfaction with existing communication systems (38% mainly good; 7% extremely good). 11% stated that their satisfaction is ‘not good’, while 4% stated that their satisfaction with communication tools is ‘not good at all’. Overall satisfaction can be judged as being good when it comes to communication tools used on construction-sites.

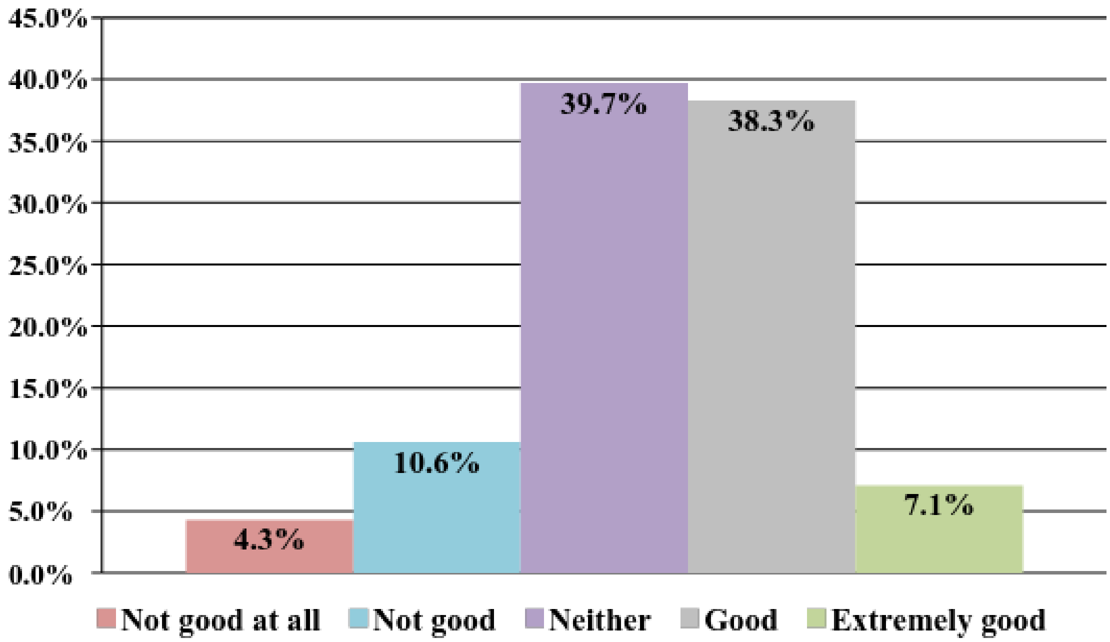


Figure 5-5: The frequency of answers that related to the communication satisfaction

5.3.2.3. The Communication tools Currently in Use on Construction Sites

Respondents rated communication tools in use at the time of research on construction-sites. Seven communication tools were rated (phone calls, paper-based communication, text messages, computers, cameras, radio and fax). Participants were asked to rate, using a 5 point scale, the levels to which such tools are used. The scale ranged between 'not used at all' and 'frequently used'. By looking at all the tools and observing descriptive statistics it was found that phone calls are the most frequently used communication tool in construction with SI = 85.96%, followed by cameras and paper-based communication with SI = 77.16% and 75.74% respectively. Table 5-3 shows the results for each of the communication tools, ranked from the most used to the least used tools. Moreover, the severity index (SI) was used to rank the factors according to their significance. The SI computation is shown by Equation 1 below.

$$SI = \left(\sum_{i=1}^{5} wi \times fi\right) \times \frac{100\%}{n}$$

Figure 5-6: The severity index (SI) equation (Elhag et al., 2005; Ji and Domingo, 2014)

Where i represents the ratings 1–5, fi the frequency of responses, n the total number of responses and wi the weight for each rating. The weight for each rating is calculated by Equation 2 as seen below.

Figure 5-7: The weight for rating (Elhag et al., 2005; Ji and Domingo, 2014)

Table 5-3: The SI, mode and median of the communication tools that utilised in construction-site

Types of communication tools	Not used at all	Not Used	Neither	Used	Extremely Used	Mode	Median	SI	Rank
A. Phone Calls	6.4%	2.1%	9.9%	18.4%	63.1%	**5.0**	**5.0**	**85.96%**	**1**
E. Cameras	5.0%	7.1%	19.9%	33.3%	34.8%	**5.0**	**4.0**	**77.16%**	**2**
B. Paper-Based	7.8%	5.0%	17.7%	39.7%	29.8%	**4.0**	**4.0**	**75.74%**	**3**
D. Computes	6.4%	4.3%	30.5%	22.7%	36.2%	**5.0**	**4.0**	**75.60%**	**4**
F. Fax	12.1%	17.7%	37.6%	18.4%	14.2%	**3.0**	**3.0**	**60.99%**	**5**
G. RIDO	31.9%	9.9%	19.1%	23.4%	15.6%	**1.0**	**3.0**	**56.17%**	**6**
C. Text messages	22.0%	22.7%	33.3%	12.8%	9.2%	**3.0**	**3.0**	**52.91%**	**7**

5.3.3. The Information Requirements that Exchange On-site Construction (At The Point of Work)

This section is concerned with the information requirements on construction sites; overall this was reflected in a scale that includes 29 items. Theoretically these items represent four main categories according to Cox *et al.* (2002), as seen in Section 3.4.3: construction field activity and progress logs; resource and inventory logs, including tracking of labourers, equipment, and materials; change order and submittal requests and quality control and assurance records. In this section, the researcher will consider all items together and evaluate the items that generated the highest and lowest importance overall. Each category of item will then be looked at separately. Overall, it was observed that "viewing a drawing" is the information most required on-site with SI = 84.96%; this was followed by "quality assurance" (82.13%), "quality inspections" (SI = 81.28%) and the "field observation" (SI = 80.71%). These were judged the most important information requirements. The least important ones were found to be "weekly report" (SI = 69.22%) followed by "changing orders" (SI = 67.94%), "on-site accounting of operatives/visitors" (SI = 67.52%) and the least rated in terms of importance was "monthly reports" (SI = 62.55%).

Table 5-4: The frequencies, mode, median and rank of the information required on construction-site

Types of information	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
Y. View a drawing	4.3%	5.0%	7.8%	27.7%	55.3%	**5.0**	**5.0**	**84.96%**	**1**
D. Quality assurance	5.7%	8.5%	12.1%	17.0%	56.7%	**5.0**	**5.0**	**82.13%**	**2**
M. Quality inspections	4.3%	9.9%	11.3%	24.1%	50.4%	**5.0**	**5.0**	**81.28%**	**3**
F. Field observations	4.3%	2.1%	20.6%	31.9%	41.1%	**5.0**	**4.0**	**80.71%**	**4**
C. Task allocation	5.7%	2.1%	19.1%	29.8%	43.3%	**5.0**	**4.0**	**80.57%**	**5**
A. Requests for information	6.4%	5.7%	13.5%	28.4%	46.1%	**5.0**	**4.0**	**80.43%**	**6**
Q. Site investigation	5.7%	2.8%	20.6%	30.5%	40.4%	**5.0**	**4.0**	**79.43%**	**7**

I. Monitoring health and safety on-site	7.1%	11.3%	10.6%	19.9%	51.1%	**5.0**	**5.0**	**79.29%**	**8**
P. accident reporting	5.7%	7.8%	14.9%	29.1%	42.6%	**5.0**	**4.0**	**79.01%**	**9**
G. Monitoring progress	5.7%	9.9%	14.2%	24.8%	45.4%	**5.0**	**4.0**	**78.87%**	**10**
U. Material Management	6.4%	5.0%	16.3%	34.0%	38.3%	**5.0**	**4.0**	**78.58%**	**11**
J. Daily report	4.3%	6.4%	19.9%	34.0%	35.5%	**5.0**	**4.0**	**78.01%**	**12**
E. work directory	5.0%	5.7%	22.0%	33.3%	34.0%	**5.0**	**4.0**	**77.16%**	**13**
R. Exception reporting	5.0%	16.3%	13.5%	22.0%	43.3%	**5.0**	**4.0**	**76.45%**	**14**
CC. Read methods statement	5.0%	5.0%	32.6%	17.7%	39.7%	**5.0**	**4.0**	**76.45%**	**15**
O. schedule updates	4.3%	6.4%	22.0%	37.6%	29.8%	**4.0**	**4.0**	**76.45%**	**16**
L. Delay recording	2.1%	9.9%	22.7%	35.5%	29.8%	**4.0**	**4.0**	**76.17%**	**17**
S. equipment management	5.0%	5.7%	34.0%	20.6%	34.8%	**5.0**	**4.0**	**74.89%**	**18**
W. Activity Duration	2.1%	10.6%	27.0%	31.2%	29.1%	**4.0**	**4.0**	**74.89%**	**19**
AA. Annotate a drawing	3.5%	4.3%	37.6%	25.5%	29.1%	**3.0**	**4.0**	**74.47%**	**20**
N. Reporting violations	5.0%	10.6%	27.0%	27.7%	29.8%	**5.0**	**4.0**	**73.33%**	**21**
T. Site diaries	1.4%	9.9%	39.0%	21.3%	28.4%	**3.0**	**3.0**	**73.05%**	**22**
H. Work package information	5.0%	8.5%	31.9%	27.0%	27.7%	**3.0**	**4.0**	**72.77%**	**23**
X. Defect management	2.1%	8.5%	39.0%	30.5%	19.9%	**3.0**	**4.0**	**71.49%**	**24**
B. Subcontractor information	4.3%	12.1%	33.3%	27.7%	22.7%	**3.0**	**4.0**	**70.50%**	**25**
Z. Weekly report	7.8%	9.2%	33.3%	28.4%	21.3%	**3.0**	**3.0**	**69.22%**	**26**
K. changing orders	4.3%	21.3%	30.5%	18.4%	25.5%	**3.0**	**3.0**	**67.94%**	**27**
V. On-site accounting of operatives/visitors	5.0%	11.3%	43.3%	22.0%	18.4%	**3.0**	**3.0**	**67.52%**	**28**
BB. Monthly report	9.9%	17.0%	36.9%	22.7%	13.5%	**3.0**	**3.0**	**62.55%**	**29**

1. Construction field activity and progress logs

"Viewing a drawing" (SI = 84.96%) was ranked first in terms of importance, followed by "field observations" (SI = 80.71%) and, thirdly, the "task allocation" (SI = 80.57). At the end of the scale "report violations" (SI = 73.33%) preceded "work package information" (SI = 72.77%).

Table 5-5: The factor of construction field activity and progress logs

Types of information	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
Y. View a drawing	4.3%	5.0%	7.8%	27.7%	55.3%	**5.0**	**5.0**	**84.96%**	**1**
F. Field observations	4.3%	2.1%	20.6%	31.9%	41.1%	**5.0**	**4.0**	**80.71%**	**2**
C. Task allocation	5.7%	2.1%	19.1%	29.8%	43.3%	**5.0**	**4.0**	**80.57%**	**3**
Q. Site investigation	5.7%	2.8%	20.6%	30.5%	40.4%	**5.0**	**4.0**	**79.43%**	**4**
I. Monitoring health and safety on-site	7.1%	11.3%	10.6%	19.9%	51.1%	**5.0**	**5.0**	**79.29%**	**5**
G. Monitoring progress	5.7%	9.9%	14.2%	24.8%	45.4%	**5.0**	**4.0**	**78.87%**	**6**
E. work directory	5.0%	5.7%	22.0%	33.3%	34.0%	**5.0**	**4.0**	**77.16%**	**7**
CC. Read methods statement	5.0%	5.0%	32.6%	17.7%	39.7%	**5.0**	**4.0**	**76.45%**	**8**
O. schedule updates	4.3%	6.4%	22.0%	37.6%	29.8%	**4.0**	**4.0**	**76.45%**	**9**
L. Delay recording	2.1%	9.9%	22.7%	35.5%	29.8%	**4.0**	**4.0**	**76.17%**	**10**
W. Activity Duration	2.1%	10.6%	27.0%	31.2%	29.1%	**4.0**	**4.0**	**74.89%**	**11**
AA. Annotate a drawing	3.5%	4.3%	37.6%	25.5%	29.1%	**3.0**	**4.0**	**74.47%**	**12**
N. Reporting violations	5.0%	10.6%	27.0%	27.7%	29.8%	**5.0**	**4.0**	**73.33%**	**13**
H. Work package information	5.0%	8.5%	31.9%	27.0%	27.7%	**3.0**	**4.0**	**72.77%**	**14**

2. Chronological files of project correspondence and memorandums, including RFIs

In this category of information exchange, it was observed that “requests for information” were ranked as the most important information exchange (SI = 80.43%), followed by “daily reports (78.01%). The least ranked two items were “weekly report” (SI = 69.22%) and “monthly reports” (SI = 62.55%).

Table 5-6: Items that fall in chronological files of project correspondence and memorandums factor

Types of information	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
A. Requests for information	6.4%	5.7%	13.5%	28.4%	46.1%	**5.0**	**4.0**	**80.43%**	**1**
J. Daily report	4.3%	6.4%	19.9%	34.0%	35.5%	**5.0**	**4.0**	**78.01%**	**2**
T. Site diaries	1.4%	9.9%	39.0%	21.3%	28.4%	**3.0**	**3.0**	**73.05%**	**3**
B. Subcontractor information	4.3%	12.1%	33.3%	27.7%	22.7%	**3.0**	**4.0**	**70.50%**	**4**
Z. Weekly report	7.8%	9.2%	33.3%	28.4%	21.3%	**3.0**	**3.0**	**69.22%**	**5**
BB. Monthly report	9.9%	17.0%	36.9%	22.7%	13.5%	**3.0**	**3.0**	**62.55%**	**6**

3. Resource and inventory logs, including tracking of labourers, equipment, and materials

The table below reflects items under the category of resources and inventory logs, where "accident reporting" was considered to be the most important (SI = 79.01%) and "on-site accounting of operative/visitors" (SI = 67.52%) was considered to be the least important type of information required.

Table 5-7: Resource and inventory logs, including tracking of labourers, equipment, and materials factor

Types of information	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
P. accident reporting	5.7%	7.8%	14.9%	29.1%	42.6%	**5.0**	**4.0**	**79.01%**	**1**
U. Material Management	6.4%	5.0%	16.3%	34.0%	38.3%	**5.0**	**4.0**	**78.58%**	**2**
S. equipment management	5.0%	5.7%	34.0%	20.6%	34.8%	**5.0**	**4.0**	**74.89%**	**3**
V. On-site accounting of operatives/visitors	5.0%	11.3%	43.3%	22.0%	18.4%	**3.0**	**3.0**	**67.52%**	**4**

4. Quality control records

The table below shows the quality control records comprising three items. Out of the three "quality assurance" was ranked the highest in importance (SI = 82.13%) followed by "quality inspections" (SI = 81.28%).

Table 5-8: Quality control and assurance records factor

Types of information	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
D. Quality assurance	5.7%	8.5%	12.1%	17.0%	56.7%	**5.0**	**5.0**	**82.13%**	**1**
M. Quality inspections	4.3%	9.9%	11.3%	24.1%	50.4%	**5.0**	**5.0**	**81.28%**	**2**
X. Defect management	2.1%	8.5%	39.0%	30.5%	19.9%	**3.0**	**4.0**	**71.49%**	**3**

5. Change order and submittal requests

The table below shows the change order and submittal requests. This was represented by two items, namely "exception reporting" (SI = 76.45%) and "changing orders" (SI = 67.94%).

Table 5-9: Change order and submittal requests

Types of information	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
R. Exception reporting	5.0%	16.3%	13.5%	22.0%	43.3%	**5.0**	**4.0**	**76.45%**	**1**
K. changing orders	4.3%	21.3%	30.5%	18.4%	25.5%	**3.0**	**3.0**	**67.94%**	**2**

5.3.4. Barriers to The Adoption of On-Site Mobile Computing Technology

This section is concerned with barriers: technical barriers and organisational issues related to the characteristics of the construction industry. Questionnaire respondents were presented with a list of possible barriers to the on-site adoption of mobile computing technology. It was found that 'The effect of existing management' (SI = 79.72%) was rated the most important challenge followed by 'The availability of training support' (SI = 78.87%); 'The user's' work requirements' (SI = 77.87%) and the 'The effect of the device's screen size' (SI = 77.73%). The difference between these challenges was marginal. At the other end of the scale, the least ranked challenges were 'The device capabilities' (SI = 66.81%); 'The complexity of mobile application' (SI = 66.38%) and 'The effect of social influence' (SI = 63.97%). The least ranked challenge was found to be the 'The level of education of the diversity of nationals' (SI = 62.84%).

Table 5-10: The percentages, mode, median and rank of barriers to the adoption of on-site mobile computing in construction

Challenges	Not important at all	Not important	Neither	Important	Very important	Mode	Median	SI	Rank
R. The effect of existing management practices that reluctant to change when implementing mobile	6.4%	2.8%	22.7%	22.0%	46.1%	**5.0**	**4.0**	**79.72%**	**1**
S. The availability of training support on the uptake of mobile computing	6.4%	7.1%	16.3%	26.2%	44.0%	**5.0**	**4.0**	**78.87%**	**2**
V. The user's' work requirements affect the adoption of mobile computing	6.4%	4.3%	27.0%	20.6%	41.8%	**5.0**	**4.0**	**77.87%**	**3**
G. The effect of the device's screen size on which data are displayed	5.7%	5.0%	21.3%	31.2%	36.9%	**5.0**	**4.0**	**77.73%**	**4**
J. The diversity of terminology and semantics among project members' effects the mobile adoption	12.8%	5.0%	12.1%	29.8%	40.4%	**5.0**	**4.0**	**76.03%**	**5**
U. The effect of top management support on the uptake of mobile computing	7.1%	7.1%	19.1%	31.9%	34.8%	**5.0**	**4.0**	**76.03%**	**6**

E. The effect of the device's screen clarity on presenting the project information	7.1%	6.4%	15.6%	41.1%	29.8%	**4.0**	**4.0**	**76.03%**	**7**
W. The effect of staff proficiency in IT skills on mobile computing	5.7%	11.3%	17.7%	34.8%	30.5%	**4.0**	**4.0**	**74.61%**	**8**
C. The Device performance that affect mobile adoption	5.0%	8.5%	24.1%	35.5%	27.0%	**4.0**	**4.0**	**74.18%**	**9**
M. The effect of high level of entities in the project on the adoption of mobile computing	4.3%	7.1%	29.8%	33.3%	25.5%	**4.0**	**4.0**	**73.76%**	**10**
N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.	3.5%	12.1%	29.8%	24.8%	29.8%	**3.0**	**4.0**	**73.05%**	**11**
A. The data security issue effect utilising mobile computing	7.1%	6.4%	28.4%	32.6%	25.5%	**4.0**	**4.0**	**72.62%**	**12**
L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device	7.1%	15.6%	14.9%	36.2%	26.2%	**4.0**	**4.0**	**71.77%**	**13**
F. The data entry and display approaches effect adopting mobile computing	6.4%	19.1%	17.7%	23.4%	33.3%	**5.0**	**4.0**	**71.63%**	**14**
Q. The diversity of project members' languages effects the mobile adoption	6.4%	12.1%	29.8%	24.8%	27.0%	**3.0**	**4.0**	**70.78%**	**15**
B. The effect of battery consumption on utilising of mobile device	3.5%	9.9%	36.2%	29.8%	20.6%	**3.0**	**4.0**	**70.78%**	**16**
T. The effect of users' attitude on the acceptance of mobile computing	5.7%	7.8%	38.3%	25.5%	22.7%	**3.0**	**3.0**	**70.35%**	**17**
K. The portability (size and weight) of the device effect adopting mobile device	5.7%	17.0%	24.8%	31.2%	21.3%	**4.0**	**4.0**	**69.08%**	**18**
D. The availability of technical support on the uptake of mobile computing	5.0%	14.9%	34.8%	27.7%	17.7%	**3.0**	**3.0**	**67.66%**	**19**
H. The device capabilities that impact on the mobiles' utilisation	8.5%	9.9%	37.6%	27.0%	17.0%	**3.0**	**3.0**	**66.81%**	**20**
I. The effect of the complexity of mobile application on adopting mobile computing	6.4%	14.2%	38.3%	23.4%	17.7%	**3.0**	**3.0**	**66.38%**	**21**
P. The effect of social influence on the user's adoption of mobile computing	6.4%	19.1%	34.8%	27.7%	12.1%	**3.0**	**3.0**	**63.97%**	**22**
O. The level of education of the diversity of nationals (Multicultural) effect the mobile Implementation	16.3%	10.6%	37.6%	13.5%	22.0%	**3.0**	**3.0**	**62.84%**	**23**

5.3.5. The Suggested Mobile Devices to be Used for On-site Construction Communication

A significant majority of respondents (74%) nominated the smart-phone as the most appropriate technology for use by construction personnel to exchange information on-site. 20% of the sample recommended the tablet, while the remaining 6% suggested the laptop.

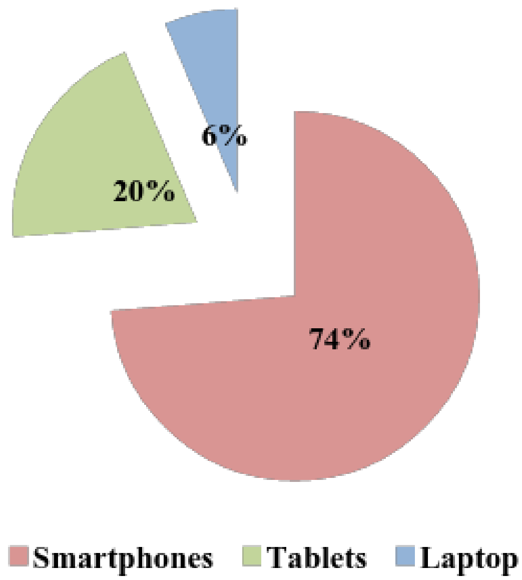


Figure 5-8: The suggested mobile devices to be used

5.4. Factor Analysis: The Challenges Affecting the Adoption of Mobile Computing Technology

It is the nature of some social science studies to be concerned with measurement of the immeasurable or unquantifiable (so-called latent variables). Field (2009) indicated that factor analysis techniques have three main purposes:

- To understand the structure of a set of variables.
- To design a questionnaire to quantify an underlying variable.
- To minimise and transform an amorphous set of data to the extent that it becomes meaningful and more tractable, while retaining as much of its characteristic elements as possible.

Factor principle component analysis was used in this study to isolate latent variables within the challenges scale (challenges facing the adoption of mobile technology). In this factor analysis, the researcher used Varimax Rotation including loadings above the value of 40% (0.4). To determine the number of factors/components extracted from this scale/data, the researcher used an eigenvalue of 1, hence any component above this value is considered a latent variable that can combine a number of items within it (Tables 5-12).

It is important to ensure that the sample size is adequate to conduct the factor principle component analysis. Sample adequacy is measured through the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett’s Test of Sphericity. Kaiser (1974) recommends a bare minimum of 0.5 where values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good, values between 0.8 and 0.9 are great and values above 0.9 are superb. The KMO value for these data was set at = 0.891, which falls into the superb range, meaning that the sample size is adequate for factor analysis. The Bartlett test of Sphericity was significant: $X^2(253) = 2371.53$, $p = 0.000$; hence, the sample can be considered adequate for factor analysis use.

Table 5-11: KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.891
Bartlett's Test of Sphericity	Approx. Chi-Square	2371.528
	Df	253
	Sig.	.000

5.4.1. Factor Extraction

The aim of factor extraction is to pinpoint how many factors (components) would be retained in the analysis (Field, 2005). The scree plot, as Cattell (1966b) explains, is a graph showing each eigenvalue (Y-axis) against the factor with which it is associated (X-axis) as shown in (Figure 5-9). Cattell (1966b) argues that the cut-off point for selecting factors should be at the point of inflexion of this curve. The point of inflexion is where the slope of the line changes dramatically. Kaiser (1960) recommended retaining all factors with eigenvalues greater than 1. This criterion is based on the idea that the eigenvalues represent the amount of variation explained by a factor and that an eigenvalue of 1 represents a substantial amount of variation.

Scree plot is a useful way of establishing how many factors should be retained in an analysis. By observing the table of total variances (Table 5-12) and factor extraction it was evident that overall there were 4 factors/components, all of which have an eigenvalue of 1 or above. Component 1 explained 45.04% of the variances before rotation and 23.47% after rotation. Component 2 explained 9.47% of the variances before rotation and 18.22% after rotation, Factor 3 explained 7.89% of the variance before the rotation and 15.62% after rotation and, finally, Factor 4 explained 6.15% of the variances before rotation and 11.24% after rotation. Overall, the four factors explain 68.56% of the variances in the data.

Table 5-12: The eigenvalue for each factor (component)

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	10.360	45.045	45.045	10.360	45.045	45.045	5.399	23.475	23.475
2	2.179	9.475	54.521	2.179	9.475	54.521	4.192	18.226	41.701
3	1.815	7.893	62.414	1.815	7.893	62.414	3.593	15.620	57.321
4	1.415	6.151	68.565	1.415	6.151	68.565	2.586	11.244	68.565
5	.814	3.538	72.104						
6	.766	3.330	75.434						
7	.717	3.118	78.551						
8	.670	2.913	81.465						
9	.511	2.221	83.685						
10	.486	2.112	85.797						
11	.418	1.819	87.616						

12	.395	1.715	89.331						
13	.375	1.630	90.961						
14	.353	1.537	92.498						
15	.310	1.347	93.845						
16	.282	1.227	95.071						
17	.251	1.090	96.161						
18	.225	.980	97.141						
19	.173	.753	97.894						
20	.160	.695	98.589						
21	.144	.627	99.215						
22	.105	.456	99.671						
23	.076	.329	100.000						
Extraction Method: Principal Component Analysis.									

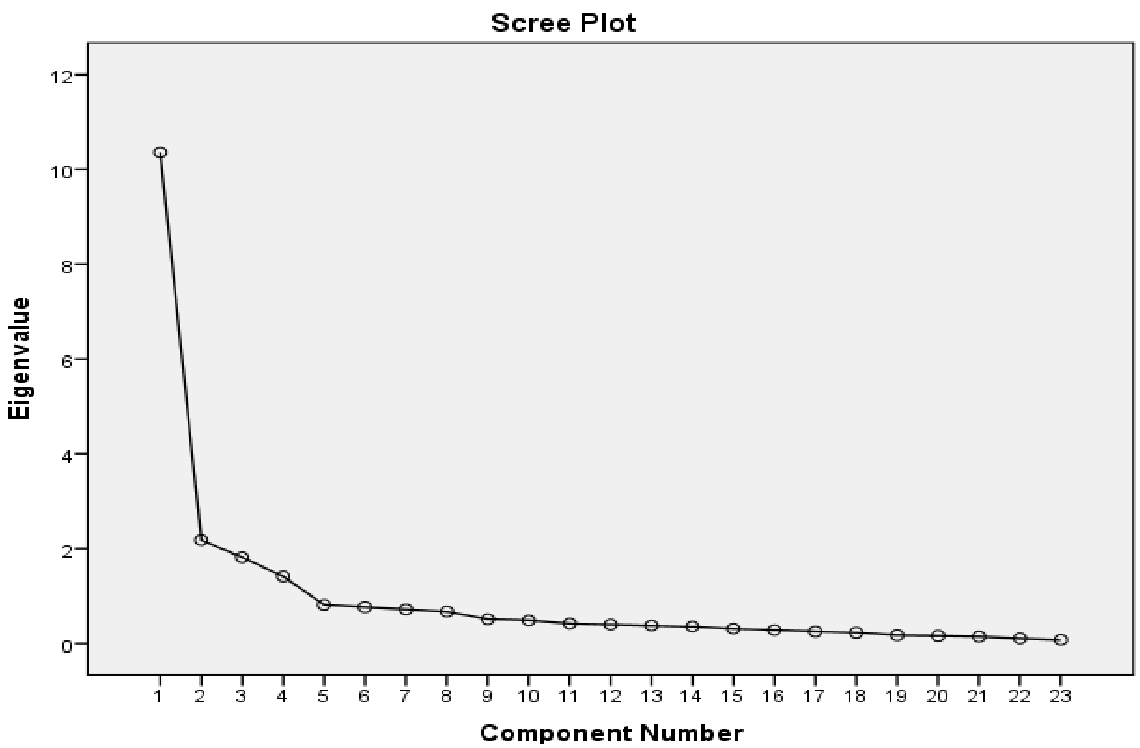


Figure 5-9: The scree plot

5.4.2. Varimax Rotation

In this section of the factor analysis, the varimax rotation allows for items to be loaded on corresponding factors; this enables the researcher to work out which item loads highest in each of the components. Rotation can be classified into two types: orthogonal rotation and oblique rotation. In orthogonal rotation, the factors remain uncorrelated while in oblique rotation the factors are allowed to correlate. The varimax method is the most commonly used method for orthogonal rotation where the objective is to minimise the number of variables that have high loadings on a factor. By looking at the rotated component matrix (Table 5-13), it can be seen that the items fall under four categories, as follows:

- Component 1: There are 6 items loaded highly in this component, all items reflecting challenges of mobile computing technology that related to "Management".
- Component 2: This component includes 6 items reflecting challenges regarding "Technology".
- Component 3: This component has 7 items reflecting challenges related to "Usability".
- Component 4: This component has 4 items reflecting challenges related to "Culture".

Table 5-13: Factor analysis

Factors	Item	Factor			
		1	2	3	4
Management	v. The user's' work requirements	.877			
	s. The training support	.859			
	u. Top management support	.839			
	w. Staff proficiency in IT skills	.742			
	r. The existing management practices	.714			
	t. The users' attitude	.647			

Technology	e. Screen clarity		.845		
	a. The security of information		.792		
	c. Device performance		.764		
	d. The technical support		.739		
	b. The battery duration		.654		
	h. The device capacity		.521	.443	
Usability	i. The complexity of mobile application			.801	
	l. Construction conditions (e.g. temperature, humidity, dust, etc.)	.460		.659	
	k. The portability	.434		.655	
	f. Input and output methods			.608	
	q. Multilingual	.474		.594	
	j. Semantics / jargon	.535		.570	
	g. Screen size		.507	.522	
Culture	p. The effect of social influence				.775
	n. work habits				.771
	m. high level of entities				.711
	o. The level of education of the diversity of nationals				.648
	Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation.				
	a. Rotation converged in 6 iterations.				

5.5. Summary

This chapter has generated interesting results in relation to the main aim and goals of the study. It began with the Respondent Background section (Section 5.3.1), which contains an important question that categorises the participants who returned the questionnaire according to their area of work. This categorisation is needed as this question aimed to filter the respondents by their area of work; as the target population for this study was participants working in contractor companies, other respondents were excluded. However, just over two thirds - 68.8% (141) – of respondents were found to be working in contractor firms.

This chapter has presented the results that show that the communication tools used in KAS construction sites presently are in line with the conclusions of the literature review, which are that the existing communication systems are traditional. This chapter concluded with Section 5.4, the factor analysis, which allows for items to be allocated to corresponding factors; this enables the researcher to decrease the number of variables (23) to factors (4) regarding the challenges that affect the adoption of mobile computing technology (Tables 5-13). This helps to recognise the structure of the variables and identify the relevant factor accordingly. The questionnaire results are used to inform an understanding of the current situation in KSA, to build the interviews, which are presented in the next chapter in Section (6.4.4), and to enhance the generalisability of the qualitative study. In the next chapter, the highest attention will be to summarise the main findings from qualitative methods. The findings will be revised and discussed in relation to previous findings and in the context of Saudi Arabia later in chapter 7. It should be noted that the descriptive analysis are of greater interest and the discussion will mainly focus on them.

Chapter 6: Qualitative Data Results

6.1. Chapter Overview

This chapter summarises the key findings from the research case studies. The rationale for the case studies was presented in Chapter 4, while the process of undertaking a qualitative study was described in Sections 4.5 and 4.8.3. This chapter outlines the most important phases of the research process, which aided in developing a comprehensive understanding of the research topic, the communication tools used at the time, and relevant issues related to mobile computing usage in Saudi construction sites. Survey findings contributed to this chapter and both were later used in Chapter 7 to discuss and guide the development of the framework strategy in Chapter 8. The answers to the interview questions, as well as the researcher's observations, are presented and discussed in the following sections.

6.2. Introduction

This chapter presents the findings yielded by three case studies. These three projects were public projects. The case studies were selected according to their size and the reputation of the contractor companies involved. The Ministry of Municipal and Rural Affairs in Saudi has classified the contractors into five levels according to their scope of work. Each level has a list of requirements which the contractor companies aim to meet in order to upgrade their position to a higher level and be awarded bigger, better remunerated and more complex projects. The Ministry evaluates the contractors according to their value asset, work performance, etc.

The projects were large and complex which required the involvement of a large number of staff members. The workers on these construction projects provided useful data to build an understanding of the general conditions and circumstances on Saudi construction sites, to identify the information needs of on-site construction personnel, and the current communication tools that construction personnel use to exchange and manage site information. In addition, these case studies provided an insight into the staff's opinion on the challenges that affect the adoption of mobile computing.

6.3. Profile of Projects and Interviewees

The cases chosen were large and complex ongoing construction projects. The individual identified as case study A is engaged in constructing an infrastructure utility (Chiller Building) for a number of new university buildings. Case study B is constructing four College Buildings for a university. The contractors executing projects A and B were classified in the first level in the category "Buildings". Contractor C is constructing part of the Fourth Ring Road (New Highway) with a big junction and its contractor is classified in the second level in the category of "Roads" according to the Saudi Agency of the contractors classification in the Ministry of Municipal and Rural Affairs (MACC, 2013).

The researcher met with each interviewee in a quiet location which was conducive to reflective thought. Following an introductory briefing about the research background and its goals, the researcher commenced the interviews which were audio-recorded. All interviews were then transcribed, translated into English and analysed using content analysis and thematic analysis techniques. The researcher read his observations' notes as well as all ten interviews several times and analysed the scripts by extracting a number of themes arising from the most commonly-expressed views and opinions of the interviewees. The themes were generated through codes created on the basis of the replies given; findings were grouped to form relevant themes in response to the questions asked. A total of 10 participants expressed their opinions and ranked pre-selected statements concerning the benefits, the procedures and difficulties of using mobile computing in a construction environment. Table 6-1 provides a list of the participants (initials are used to ensure confidentiality).

Table 6-1: The interviewees' information

Case study	Initials	Job of interviewees
A	A1	Site supervisor
	A2	Structure Site Engineer
	A3	Architectural Site Engineer
B	B1	Construction Manager
	B2	Site Manager 1
	B3	Site Engineer 1-1
	B4	Site Engineer 1-2
C	C1	Project Manager
	C2	Site Engineer
	C3	Site Engineer

6.4. Findings

The interview asked a mix of open-ended and closed questions (Appendix C). The time taken to complete interviews was approximately one hour. After a comprehensive reading of the interview scripts, the researcher analysed the details of the responses, relating them to the research themes. The interview comprised the following four sections: construction communication, on-site information requirements and the methods of communication, attitudes to mobile computing technology, and the key challenges that may affect its implementation.

6.4.1. Construction Communication

The objective of this section is to identify the communication tools currently in use, the reasons for their use and the attitudes and opinions held by construction personnel about alternative communication tools. The following points reflect the main replies provided by interviewees.

6.4.1.1. Communication Tools

Based on the researcher's observations and the responses from interviewees in the case studies, the three principal communication tools used by the site engineers are: voice phone calls, paper based (letters/ reports), and emails. The main tool in constant use is voice phone calls. Voice phone calls are the predominant means of communication used both on-site and in the site offices to exchange information, issue orders, receive immediate updates, and to track engineers for any reason that requires immediate action. Interviewee A1 said that "around 90% of our on-site communication is via voice phone calls". However, words can be misheard and meaning misinterpreted, with only the memory (rather than a written or digital record) as an unreliable guide to the original content. Therefore, "misunderstandings" sometimes occur as C1, C2 and B3 indicated. "Signal problems" (stated by B1, B4, C1, C2 and C3) and "limited battery life" (stated by B1, A1) were the two main issues restricting on-site use for making calls.

The use of paper documents is divided into two forms of communications: limited fill-in forms and formal reports. Fill-in forms are standard on construction sites used mainly for the purpose of making requests and issuing warnings but are susceptible to loss or damage and delays. Completing and processing the information they contain is a time consuming process. Formal reports are prepared at on site offices because interviewees much prefer to type using PCs. Printers and scanners are available at site offices to produce a final and complete report. Email is used to send documents such as final reports to senior management. A1 indicated that paper based communication is used for "routine" purposes.

The immediacy and synchronicity of phone calls – a conversation and a response is guaranteed in real time – contrast with the awkwardness of typing emails on-site. For this reason, only B2 uses an email App on his smartphone to check if he has received emails when on-site. Email is used at site offices mostly by site engineers preparing formal reports for their superiors or communicating with other departments. B1 indicated that “we use emails to communicate with the upper management or other departments only” (90% of such communication is by email, 10% voice calls). But paper reports are used for circulating the day-to-day work plans and work rotas.

The use of emails on-site is limited because, firstly, formality is not generally required on-site; secondly, the most appropriate medium for passing information is voice calls; and thirdly, a synchronous medium (voice calls) delivers an immediate response. When B1 sends an email “not everybody will see it immediately, especially the site engineers, because they are working on-site”. They “probably will see it at the end of the day in the site office and we need an immediate reaction to get things done”. In other words, where matters of importance are concerned, and when there is time for reflection, the written word is the most appropriate medium, but writing requires conditions which make reflection and clear thought possible, and these conditions do not occur often on-site.

6.4.1.2. Other Communication Tools

In this section, interviewees were asked about other tools they use. Photos and, to a lesser extent, videos are used from time to time to support reports or meetings. Text messages are not used commonly for reasons to do with time, literacy, their perceived utility for information exchange and the expectation they will, most likely, not get an immediate response. C2, A1, B1, B3 and B4 used Walkie-Talkies before they started using voice phone calls. C2 and B1 stated that Walkie-Talkies retain their usefulness for remote projects where there is no mobile signal. A1 stated that “Voice phone calls are better than Walkie-Talkies” but B4 disagreed. He explained that “Walkie-Talkies speed-up communication because site engineers and foremen merely need to press a button to activate a pre-entered calling code, the equivalent of speed-dialling, to be connected.” This small detail illustrates a larger point; when operatives whose priority is job completion assess digital technologies for on-site use, the pressure to get the job done and onerous on-site conditions make speed and user friendliness a priority.

Several interviewees (A1, A2 and A3) indicated they used WhatsApp when the issue is urgent or when they want to use an image to illustrate a point. There is no precedent for building a routine store of evidential photographic information. Photos are used as explanatory evidence in situations where there are problems on-site. In these instances, it is said, a ‘picture is worth a 1000 words’. Considerations of time and the insufficiency of the written word to describe what a picture instantly communicates were confirmed by the site supervisor. (A1) explained that he uses WhatsApp when a problem occurs on the site and he is “busy and cannot leave the office, then A2 or A3 will contact me by voice phone call to inform me of the status and he will take photos (via phone camera) and send it via WhatsApp. So, I can then take action and make decisions regarding the problem and direct the site engineers (A2 and A3). Or if I need an update report quickly regarding the current status of an activity, or what progress site engineers (A2 and A3) are making, I will contact them using voice phone calls and they will take photos (via phone camera) and attach them to the WhatsApp message writing down and sending the relevant information. This evidence is then used as the basis of a paper report.”

6.4.2. Communication Processes and Key Information Requirements

This section details the key information requirements for site based construction engineers. It provides background information about the interviewees’ roles and responsibilities and provides a breakdown of the management structure to illustrate the interviewees’ position in the management hierarchy. To map the information flow described in their projects, the section describes the management practices related to the tasks they perform, how they send and receive information and who they send it to and receive it from. It also provides information about the interviewees’ role in the project.

6.4.2.1. Organisational Breakdown Structure

Firstly, it is helpful to explore the contractor’s Organisational Structure to understand their communication processes and information channels and the interviewee’s role to identify the decision makers.

Case Study A: This project concerns the construction of an infrastructure utility chiller unit for a number of new university buildings. The process involves the construction of a reinforced concrete building. At the time of the study the roof was being constructed with two engineers working on-site, an architectural site engineer (A3) and a civil site engineer (A2), and two foremen. The mechanical site engineer and the electrical site engineer will be involved on-site at a later stage. At the time of the study they were working in the main office waiting for their tasks to begin on-site. Figure 6-1 illustrates the Organisational Breakdown Structure for this project.

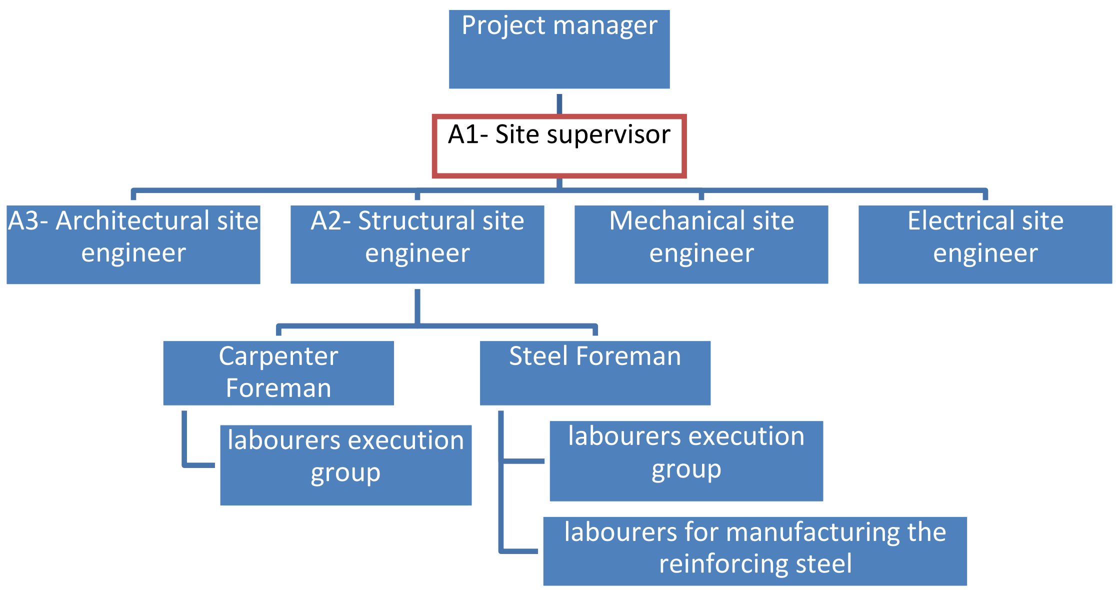


Figure 6-1: Organisational Breakdown Structure for Case Study A

Case Study B: This project is concerned with the construction of four college buildings for a university. This project is managed by a General Project Manager. The project is divided into two sections (I & II). Each section consists of two college buildings managed by a project manager. Figure 6-2 gives a breakdown of the organisational structure of one section of this project. Apart from the project manager, the project comprises two execution departments, each one with a construction manager, site manager and two site engineers with overall responsibility for the project. Beneath them in the management hierarchy are 8 supervisors and 10 foremen of limited experience who directly supervise approximately 10 labourers assigned to each building. Each building is divided into 12 zones. The state of the work at the time of the interviews had reached the building of the internal walls.

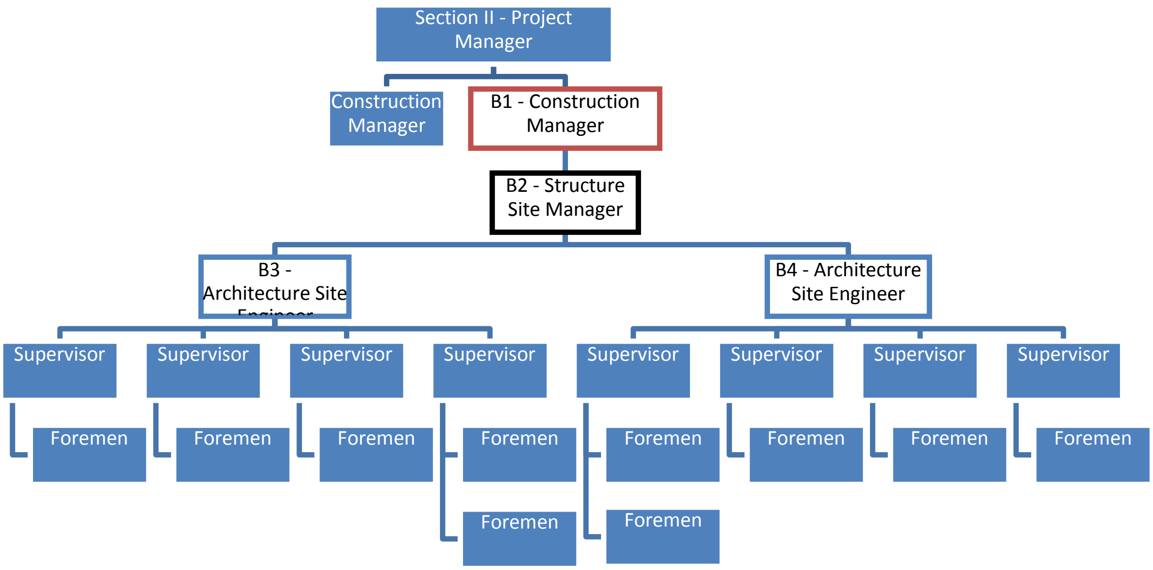


Figure 6-2: Organisational Breakdown Structure for Case Study B

Case Study C: This project concerns the construction of two kilometres of the Ring Road (New Highway) with a junction. This project is being carried out on harsh topography and requires excavation, transportation of soil, filling of certain areas and explosion of the mountainside. The project has a project manager, 6 engineers controlling 10 foremen and 6 machines. Figure 6-3 illustrates the Organisational Breakdown Structure of the project. At the time of the study, the project had reached the stage of excavation, transportation of soil, the filling of certain areas and explosion of the mountainside; the construction of the bridge junction had not yet started.

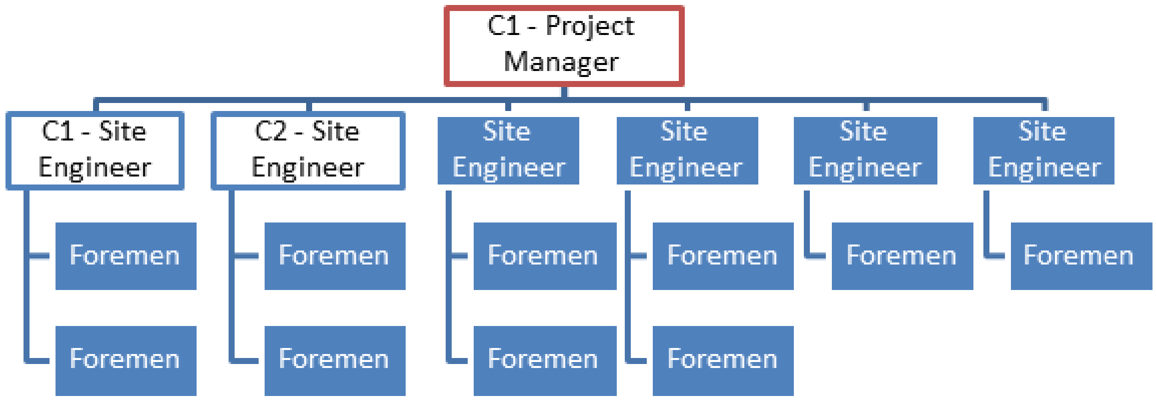


Figure 6-3: Organisational Breakdown Structure for Case Study C

6.4.2.2. Communication Processes

In Case B, where the site engineers have more opportunity to contribute to the work, they communicate in both a vertical and a horizontal direction within the project. The site engineers communicate directly with the consultant on behalf of the Construction Manager (B1) Quality Inspection of the work on site. Even the Site Manager (B2) communicates directly with the supply chain (concrete supplier) to coordinate the concrete pouring. In material requesting, for example, the site engineers in Cases A and C need permission from their managers to order materials. As described by A1 and C1, the site engineers must fill out a hardcopy form and take it to the managers for approval. They will evaluate and sometimes adjust the request after a discussion with the site engineer. Then, A1 and C1 sign the form and the site engineer will go and collect the materials. However, in Case B, where the site engineers do not have to get the Construction Manager's (B1) authority every time they need to get materials, the foreman simply asks the site engineers to sign a materials request and takes the materials directly from the warehouse. The site engineers, however, have to keep a weekly track record of the materials that they have used. Furthermore, on a monthly basis, they have to request the materials that they need with the Construction Manager (B1).

Observations of the construction company personnel at work and interviews and discussions with them revealed that the project manager in Cases A and C acts as a central command and this creates an information bottleneck. The roles and responsibilities of the site engineers are limited. C3 indicated that site engineers are not assigned to a particular task. The project manager (C1) directs the engineers on a daily basis. Communication flows from the top to the bottom. Mid-level personnel take directions from the project manager, rather than complete tasks on their own initiative and there was a clear pattern of decision making being restricted to the project managers (A and C), with little or no input from employees at lower levels. In light of this evidence from interviews and observations, in a situation where the roles and responsibilities of some management personnel reflect an autocratic style and where information flow is tightly controlled and sometimes manipulated for personal gain, the management process and the management system are indeed significant challenges to a consensual approach to implementing a collaborative system of working based on sharing and cooperation.

6.4.2.3. The information

This section details the key information requirements for site based construction engineers. The interviewees were asked about the type of information they frequently need on a daily basis. In all three cases, a daily meeting is held at the end of the day with the site engineers to organise the work (arranging the priorities) and the project time plan, assess what has been done and plan the work that needs to be done the next day to ensure that the staff and the materials are ready to start. In Cases A and B, the site engineers submit a materials request report a month ahead. These reports are based on work performance and are discussed with and approved by the project managers. This means that the materials are readily available at the store. How the work is to be delivered to the consultant for quality inspection and whose responsibility it is to deliver is also planned ahead of time. In Case C, the following week's work is dependent on the surveyors who measure the work performance each week. The surveyors have a direct link with the project manager. Therefore, C1 evaluates the work done and plans the work ahead before meeting the site engineers.

The Case B, the construction manager (B1) highlights the work directory, instructions orders, specification, work package information, schedule updates, work requirements, and monitoring progress. The site manager (B2) notes the work instructions, work directory, quality inspections, drawings, daily report, material and equipment requests, specifications, activities duration, reported violations, work package information, delay recording, monitoring of health and safety; and progress made. The site manager (B2) has a direct link of communication with the technical department to follow up on drawings and plans. Also, he authorises all external communications via reports with the consultant re quality inspections and with the owner (public sector). The site engineers B3 and B4 take care of drawing plans, daily reports, materials and equipment requests, specifications, activities duration, work package information, scheduling updates, monitoring health and safety on-site and site diaries.

The project manager (C1) and site supervisor (A1) both mentioned having to oversee materials and machinery requests, work progress reports, instruction orders, schedule updates, task allocation, work directory, daily report and quality assurance. The site engineers, in Case C, mentioned mainly drawings, specifications, the test performance form (a form to fill in when the area is ready to inspect then the quality control department will come to perform the test), materials requests, daily reports and machinery requests. Also, site engineers, in Case A, named shop drawings, specifications, material quantities, the subcontractor information, the project schedule, monitoring health and safety on-site, activity duration and delay recording.

6.4.3. Mobile Computing Technology

Having discussed the traditional methods used to communicate and share information, interviewees were asked about the possible advantages, barriers and viability of using on-site mobile computers. The interviewees were in agreement that using mobile computing will improve productivity. A1, C3 and B3 stated that it saves time and effort. B2 and A3 indicated that it would help ensure accurate and fast delivery of information. A2 indicated that it would save 50% of his time. B3 believed it would speed communication among engineers. C2 and B4 believed it would solve coordination problems as it records the progress of work. C1 and B1 stated that it will solve 50% of their communication problems; the other 50% - where lengthier explanations would be required - would be solved through voice calls or meetings. B2 stated that it will decrease the work error percentage and it will reduce misunderstanding among the engineers.

Before discussing challenges in the next section, the interviewees were asked to name the challenges that they perceive with the introduction of new technology. C1, A1 and B1 were in agreement that not all engineers have the requisite awareness and the knowledge to use the system or the technology. A2 and B1 stated that this technology should be taught at university, so they will have the latest level of knowledge. B3 was concerned about the complexity of the application and the strength of the internet signal on-site. A3 and B4 were concerned about how site conditions might affect the device.

Among the interviewees, it was notable that ease and speed of use were the common denominators determining their views regarding the perceived utility of the devices. C3 and A2 suggested training sessions should be provided to support the users. Also, A2 believed that the language of the system must be Arabic. B2 stated that the system must connect everybody to enable the sharing of project information. B3 indicated that the system should enable him to access all the project drawings, have the capacity of making voice calls and should be multilingual. A1, B1and C1 wanted a system that worked with a single app facilitating all the required information for exchange. In addition, the system should be flexible enough for the companies to modify according to their work processes.

B2 estimated he was “wasting (his) time searching for papers on a laptop” and when the sunlight made the screen unreadable, he could go back to the office to “gain information faster”. Also, B2 “keeps his mobile phone in his pocket, but in the hot weather, it becomes so hot that he cannot put it to his ear”. A3 and B4 were sure that sharing pictures and drawings with colleagues would give clarity and certainty to plans, instantly record their progress at any time, and therefore increase productivity. A poor network connection or unreliable networks can inhibit enthusiasm for mobile computer adoption. When asked about the signal on-site, several interviewees agreed that it was of reasonable quality although “sometimes the signal disappeared”. These practical considerations, which prioritise speed and convenience when communicating in difficult site conditions, call into question the reflexive enthusiasm site supervisors and project managers have shown when responding to the concept of mobile computing. They also underline, once again, that its primary application will be much more that of an information recording and sharing tool than as a communication tool, albeit one that precludes writing at length.

When the interviewees were asked to name a suitable device, A1, A3, B2 and C1 chose the tablet because of its big size. As observed by the researcher, A1 and C1 chose the tablet because they spend most of their time in the site office. A2, C2, C3, B1, B3 and B4 opted for large smartphones. B1 and B4 chose a large smartphone because it has a relatively large screen size and, unlike the Tablet, allows voice calls. B3 and B4 preferred that the device be a small size to fit in their pockets easily so they could carry it around and protect it. They indicated that the Tablet is too large to carry on construction-sites; they mentioned that they get anxious when they have their paper drawings on site. A1 stated that the Tablet is the appropriate device to use because of its portability, screen size and screen resolution; the smartphone is too small.

6.4.4. The Key Challenges to the Implementation of Mobile Computing

At the conclusion of the discussion, interviewees were asked about what possible difficulties and challenges they anticipated. To assist interviewees in structuring their thoughts and to facilitate the extraction of themes from the views and opinions they expressed, the issues of concern were divided into four categories as suggested by the questionnaires' factor analysis (Section 5.4), namely: challenges related to management, challenges related to the technology, usability challenges and cultural challenges. Each of the four categories contained six possible challenges which were ranked in order of priority of importance using the ranking feature in the Microsoft Excel. The interviewees were asked to rank the four factors according to their importance. C3, C1, A2 and B3 ranked them in the following order of priority: management, technology, usability and cultural. A1, B1, A3, C2 and B2 ranked them in this order: management, usability, technology and cultural. B4's ranking was usability, technology, management and cultural.

6.4.4.1. Management Challenges

Table 6-2: The management issues

Item	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	Ranking
U. The effect of top management support on the uptake of mobile computing	1	1	1	1	1	1	1	4	2	3	**1**
R. The effect of existing management practices that reluctant to change when implementing mobile	2	2	3	2	5	2	2	3	1	2	**2**
T. The effect of users' attitude on the acceptance of mobile computing	5	3	2	6	3	6	4	1	3	1	**3**
V. The user's' work requirements affect the adoption of mobile computing	4	4	4	4	2	5	5	2	4	5	**4**
S. The availability of training	3	5	5	5	4	3	3	5	5	4	**5**

support on the uptake of mobile computing										
W. The effect of staff proficiency in IT skills on mobile computing	6	6	6	3	6	4	6	6	6	6	**6**

The first category of challenge was labelled management challenges. 8 of the 10 interviewees ranked ‘support by the top management’ as the primary or top challenge. ‘Support by the top management’ has two fundamental connotations: financial and attitudinal. However, because ‘the availability of training support’ was another of the 6 options available, it can be safely assumed that respondents understood the issue of ‘support by the top management’, as well as the challenges of the management process (ranked 2nd of 6 challenges) and the user's acceptance (rated 3rd of 6 challenges) to refer to broadly attitudinal issues relating to management structure, styles and relationships. It is commonly accepted that an individual’s role in any organisation will determine their perspective and have a bearing on how they see their role and the roles of others.

All personnel working at construction sites A and B cited ‘support by the top management’ as the most important feature influencing the success or failure of mobile computing. The project manager (C1), occupying a more senior management role than other interviewees, perceived support by the top management as only the fourth most important of six possible management challenges. Revealingly, though not surprisingly, C1 pinpointed the attitude of the staff, that is, their reluctance or refusal to use the technology, as the most important challenge; although, overall (taking all 10 interviewee responses into account) this was rated 3rd of 6 possible challenges. This small detail hints at a larger truth; management can be remote from its workforce and is sometimes badly informed about which tools can improve their work performance.

Nevertheless, it is significant that middle-management site engineers, that is staff holding management positions but who are not part of ‘top management’ or ‘the management system’ all rated issues to do with these management processes and systems as significant challenges to be overcome. The management process – the information flow - was cited as the second most significant challenge. This research found that, when the skill-set and circumstances allow, both point of activity workers and middle management share enthusiasm for using digital technology on-site. Asked their opinion about the technology, site supervisor and project managers responded positively to the concept of its use. The attitude of these mid- management professionals is cautiously enthusiastic. Why then, one may ask, do even employees at mid-level management, in common with the majority of the findings in the literature, conclude that management support, the management process and system are among the main impediments to the success of mobile computing?.

It was not possible to interview very senior management staff, which helps explain why the reluctance of staff to use the technology was rated as only 3rd of 6 challenges. A1 indicated that the younger members of staff could not raise this issue. Firstly, while members of the staff can enthuse about a new technology, which could make their work easier without necessarily increasing profits, management must bear the responsibility of securing a return on investment with little historical precedent to support this decision. Mid-management staff members must consider the possibility that IT innovation may be impeded by the uncertainties and resentment arising from a basic conflict in management systems, between, on the one hand, a hierarchical management structure and, on the other, the interpersonal and inter-group collaborative communication processes required to implement on-site mobile computing.

The users' work requirements was ranked 4th of the 6th. B2 and C1 were concerned about this point. Any system is only as good as the information it contains and how it is programmed and structured. The project database must be set up by a project administrator. The project administrator must pre-configure data in a consistent and structured fashion so that relevant fields are pre-populated. However, it is evident that no precedent exists in a system based on "memory, experience and word of mouth" for designing and creating a project database structured around checklists and templates. A company IT administrator must configure and format files so that the on-site information can be entered and stored by a selected number of engineers to give structure to, and share, on-site processes.

Staff proficiency in IT ranked last. B1 and B3 were concerned about the inadequate computing skills of the staff. However, this could be easily remedied as the provision of training support will increase the shared knowledge and the learning resources required by the staff as C3 and A2 indicated. However, according to some interviewees, site personnel already have the capability to operate mobile devices. What is less clear is whether the company itself has the IT skills to set up a dedicated system.

6.4.4.2. Technology challenges

Table 6-3: Technology issues

Item	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	Ranking
A. The data security issue effect utilising mobile computing	1	1	1	4	1	1	1	2	1	1	**1**
D. The availability of technical support on the uptake of mobile computing	3	2	2	1	5	3	4	3	2	3	**2**
C. The device performance that affect mobile adoption	5	5	3	5	2	2	5	1	3	2	**3**
B. The effect of battery consumption on utilising of mobile device	2	3	4	2	4	5	3	6	5	4	**4**
E. The effect of the device's screen clarity on presenting the project information	4	4	6	3	6	6	2	4	6	6	**5**
H. The device capabilities that impact on the mobiles' utilisation	6	6	5	6	3	4	6	5	4	5	**6**

The security of information was considered to be the primary Technology Challenge. The loss of direct physical control over the data naturally creates concern about security among those using the technology because they feel personally responsible for keeping it safe. B1 ranked the security of information 4th out of 6 challenges. He felt that security was important because "the company is responsible for information, such as drawings, that the government considers sensitive." The technical support available was ranked as the second Technology Challenge. All the interviewees insisted on the importance of a technical unit at the project offices to help maintain the system and the mobile devices on-site.

The device performance was ranked 3rd out of 6 challenges. However, A1, A2, B1 and B4 ranked it 5th and 6th place, as they are confident about the devices. Also, as observed by the researcher, these participants were using the latest smartphones. They were, however, concerned about the battery duration while they worked on-site. Battery consumption was ranked 4th of the 6 Technology Challenges and screen resolution and visibility were ranked 5th. In this context, B4 commented that using the laptop in direct sunlight makes the screen unreadable. The last challenge related to the device abilities. A1, A2, B1 and B4 ranked this last, as they are confident about the technology given that they use the latest smartphones.

6.4.4.3. Usability challenges

Table 6-4: Usability issues

Item	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	Ranking
I. The effect of the complexity of mobile application on adopting mobile computing	1	1	1	1	1	1	1	3	5	1	**1**
F. The data entry and display	2	2	2	2	2	3	3	4	2	2	**2**

approaches effect adopting mobile computing											
L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device	7	3	4	4	6	2	4	1	1	3	**3**
K. The portability (size and weight) of the device effect adopting mobile device	3	4	3	3	4	4	2	2	7	4	**4**
J. The diversity of terminology and semantics among project members' effects the mobile adoption	5	6	5	5	5	5	5	5	3	7	**5**
Q. The diversity of project members' languages effects the mobile adoption	6	7	7	6	3	6	6	7	4	5	**6**
G. The effect of the device's screen size on which data are displayed	4	5	6	7	7	7	7	6	6	6	**7**

The main usability challenge was the perceived complexity of any proposed mobile application. The majority of interviewees stipulated that any system should be easy to use. A simple file sharing system would aid the separate planning and recording of each specialist group's work within a project. A1 requested that they be easy to use, and should be configured around a single application that holds all the information required.

Input and output methods ranked 2nd place. The majority of interviewees, particularly the site engineers, indicated that fast and easy access to the information via the device is a priority. This would determine the success or failure of the use of mobile computing. While data input is critical, the site engineers indicated that they would not be amenable to having to type in long texts. Ideally, the type of input required would be pictures which could be highlighted and annotated, tick boxes and multiple choice options, which would provide a fast and easy way to capture data.

Construction conditions (e.g. temperature, humidity, dust, etc.) was ranked 3rd, and the size and weight of the mobile was ranked 4th in the list of usability challenges. Interviewees were forgiving of physical limitations inherent to the devices' technological constraints, but were frustrated by flaws, which were exacerbated by construction conditions (e.g. temperature, humidity, dust). In this context, B4 stated that using the laptop in direct sunlight makes the screen unreadable. B2 explained he was “wasting (his) time searching for papers on a laptop” when sunlight made the screen unreadable and he often has to go back to the office to “gain information faster”. Also, B2 “keeps his mobile phone in his pocket, but in the hot weather, it becomes so hot that he cannot put it to his ear”.

The size and weight of the mobile were rated 4th out of the 6 usability challenges. A1, A3, B2 and C1chose the Tablet as their preferred device. Their decision may have been based on the fact that the tablet has a large screen and also the fact that only spend a limited time on-site. Most of the site engineers (A2, C2, C3, B1, B3 and B4) preferred Smartphones because of their relatively small size when compared with the Tablet. B3 and B4 indicated that the portability of the device is a significant feature and although they would prefer a large device it must be small enough to fit in a pocket.

Language differences between site engineers can present communication problems. As observed by the researcher, all the interviewees have Arabic as their first language. Case A and C interviewees come from the same country. Interviewees in Case A and B indicated that they used English when writing reports and communicating with non-Arabic speakers. B2 indicated that even when he sends emails and makes calls in Arabic his “emails and voice calls are misunderstood” and “they go to the site to check the problem in reality.” Communicating in Arabic makes all participants - project managers and engineers - buy into the system. However, for any system to be implemented successfully it must be ensured that the description of instructions, procedures, reports and file names should be immediately and unambiguously clear to the individuals reading them.

A discordance between formal and informal information flows was noticed. At the project level, in the three cases, there were more than five different nationalities working together on-site and problems of ambiguity arise even during voice calls. The formal language in case A and B is English. Arabic, English and other languages are the Lingua Franca and all of the related techno-speak jargon is in English causing "information not to be received accurately". Time is lost because engineers must repeat the information more than once and that "annoys" them and takes extra time and effort. Semantics and technical jargon ranked 5nd place in the list of usability challenges. The members of middle management who were interviewed did not consider semantics and technical jargon to be a problem for them when operating a mobile device as the working group has specialist knowledge.

6.4.4.4. Cultural challenges

Table 6-5: Culture issues

Item	A1	A2	A3	B1	B2	B3	B4	C1	C2	C3	Ranking
M. The effect of high level of entities in the project on the adoption of mobile computing	1	2	1	2	1	1	2	1	2	2	**1**
N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.	2	1	2	1	2	2	1	2	3	1	**2**
P. The effect of social influence on the user's adoption of mobile computing	3	3	4	4	3	3	3	3	1	4	**3**
O. The level of education of the diversity of nationals (Multicultural) effect the mobile Implementation	4	4	3	3	4	4	4	4	4	3	**4**

The fragmented nature of operations in project work was ranked 1st of the 4 issues posing challenges to the free flow of information. This fragmentation is complicated by the project-based nature of construction where the teams are temporary and on-site relationships are constantly changing which complicates the building of trust and establishment of shared goals. Work habits were ranked 2nd. Evidence shows that an individual’s role in the construction hierarchy will determine their perspective and have a bearing on how they see the role of others.

Observations of construction company personnel at work and interviews and discussions with them revealed a command-led instructional leadership style in Cases A and C which prioritised getting the job done at the expense of collaboration and individual initiative. A1 indicated that the system should be flexible in order for the companies to modify it according to their workflow and processes. As an example, A1 referred to two projects constructed by his company which have two different project management styles and Organisational Breakdown Structures. Each project has different characteristics, Organisational Breakdown Structures and allocation of different responsibilities among the staff members.

Project managers must focus on the development of managers’ capabilities to organise tasks - from a reliance on word of mouth and face-to-face instruction of a few to a more structured and accountable system based on shared responsibility. This approach would encourage collaboration and also, eventually, create values based not just on cost savings but on enhancing the quality of work and creating a pool of IT knowledge upon which the company and industry could build. As working habits affect mobile adoption, the social influence effect on the users’ adoption of mobile computing was ranked 3rd. This can be seen as a barrier to the adoption of a new way of working.

Low education challenges were rated by the ten construction professionals interviewed as the least significant of the cultural challenges. Similarly, among the usability challenges, multilingual challenges were rated 6th out of the 7 options. As the interviewees all came from one region, the language and education challenges were deemed not to have a significant effect on the adoption of mobile computing. As observed by the researcher, the contractor companies tend to employ middle management personnel from a particular country, such as is the case in Cases C and A, or from different countries as in Case B.

6.5. Summary

This chapter has generated a number of interesting results in relation to the main aim and goals of the study. It began with a Profile of Projects and Interviewees in Sections 6.2 and 6.3. The cases were selected according to their large size, complexity and classification at the top level, according to the Saudi Agency of Contractors Classification at the Ministry of Municipal and Rural Affairs (MACC, 2013). These projects thus required the involvement of a large number of staff members. The workers on these construction projects provided useful data that helped to build an understanding of the general conditions and circumstances on Saudi construction sites.

The results yielded from the questionnaire and in this chapter are similar regarding the current use of communication tools (see Sections 5.3.2.3 and 6.4.1.1). The questionnaire results in Section 5.4 regarding the challenges that affect the adoption of mobile computing technology, deduced via factor analysis, were used to organise interview questions and answers (Section 6.4.4). This process helps to assist interviewees in structuring their thoughts and to facilitate the extraction of themes from the views and opinions that are expressed. Also, it helps to simplify the answers for the researcher to document and reported. In the following chapter the main focuses to summarise the main findings from qualitative and quantitative analysis. The results will be reviewed and discussed in relation to previous findings and in the context of Saudi Arabia.

Chapter 7: Discussion of Key Data Requirements

7.1. Overview

The last two chapters have presented the data collected for this study. As the study is qualitative in nature, it used an auxiliary quantitative questionnaire to enhance the generalisability of the study. In addition, the questionnaire provides an opportunity to confirm the reliability of qualitative findings, by examining the extent to which research findings for similar questions yield similar responses. This is clearly evident in the question about the communication tools currently used in the KSA (Sections 6.4.1.1. and 5.3.2.3), which yielded similar results. Moreover, the factor analysis of the questionnaire (Section 5.4) regarding the challenges that affect the adoption of mobile computing technology enabled the researcher to decrease the number of variables (23) to 4 main factors. This helps to recognise the structure of the variables and identify the relevant factor, which was then used to organise interview questions and answers (Section 6.4.4). This also aids interviewees in structuring their thoughts, and facilitates the extraction of themes from the views and opinions they express. In addition, it simplifies the answers for the researcher to document and report. In the following sections, the main focus is to discuss the main findings of the qualitative and quantitative analysis, alongside the literature review.

7.2. Introduction

This chapter discusses the results of the data collection, and presents them to demonstrate fulfilment of the research objectives. This chapter will introduce the data collected during interviews with Saudi site based project teams, a questionnaire completed by construction professionals working in Saudi Arabia, and relevant information from the literature, to develop an understanding of the benefits and challenges involved in providing timely and relevant information to site-based construction workers. The data presented also includes key information concerning the requirements for site based construction workers in Saudi Arabia and investigates existing technology usage in Saudi Arabia by site based construction workforces.

7.3. The Existing Technology Usage in Saudi Arabia

This section discusses the communication tools currently in use, among site based personnel, building on the findings from the questionnaire and interviews as well as relevant literature. The personnel interviewed for this research explained that they use three artefacts or tools when communicating and passing information on to other project team members: voice phone calls, paper based media (letters/ reports), and emails (which requires them to go to site offices to use PCs or laptops).

According to the questionnaire and interview responses, the most frequently used communication tool on the construction-site is voice calls (Phone). This is because phones provide high mobility for personnel, either on-site or in the site offices. They offer immediacy and synchronicity, enabling team members to exchange information, issue orders, receive immediate updates, and track engineers to detect situations requiring immediate action. Interviewee A1 stated, “around 90% of our on-site communication is via Voice phone calls”. However, this creates a fundamental problem, in that words can be mis-heard and meaning can be misinterpreted; moreover, memory (rather than a written or digital record) is an unreliable purveyor of original content. In addition, there may be restricted capacity on-site for making calls, for example, half the interviewees reported “Signal Problems”.

Paper-based communication tools are the second most popular according to the interviewees. However, in the questionnaire, paper-based communication ranked in third and emails in the fourth places with severity indexes (SI) of 75.74% and 75.60% respectively, with a minor variation of 0.14%. Paper-based tools can be divided into two form of communications; hard copies, such as filling-in forms and formal reports, or those also prepared and send digitally via email. Paper-based communications are susceptible to loss or damage and delay. Completing and processing the information they contain can also be a time consuming process. Formal reports must be prepared at site offices, because they require PCs, printers and scanners. This confirms Dave et al.’s

(2010) assertion that the majority of construction projects rely on "manual processes and traditional methods of communication such as phone calls, faxes and emails to obtain such information" (Dave et al., 2010). In addition, these findings are in line with Anumba and Wang's (2012) statement, that in most construction organisations, a field team's project information access and retrieval, and information editing and decision making, are restricted to 2D paper-based technical drawings.

When site engineers prepare formal reports for their superiors and communicate with other departments they use email at site offices. B1 explained, "we use emails to communicate with the upper management or other departments only" (90% of such communication is by email, 10% involves voice calls). Otherwise, paper reports are used to circulate the day-to-day work plans and rotas. The use of emails on-site is limited for three reasons: firstly, formality is not generally required on-site, secondly, the most appropriate medium for passing information is voice calls, and thirdly, a synchronous medium (voice calls) delivers an immediate response. In other words, where matters of importance are concerned, and when there is time for reflection, the written word is deemed the most appropriate medium. However, writing requires conditions in which reflection and clear thought are possible, and these conditions do not often arise on-site.

Thus, communication is primarily by phone, and this is apparently common practice among construction-site managers: "the community of practice of the construction phase is dependent on talking" (Styhre et al., 2006, p.91). The exchange or creation of information and knowledge sharing among those working on a construction project is primarily based on "the verbal sharing of experiences, informal conversations and on 'messy talk'". (Maki and Kerosuo, 2015). The primacy of talk assigns paper reports to a reduced role. One of the main weaknesses of the current system is that paper-based reports are used infrequently as part of the "routine", as they are used for making "weekly or monthly reports by computer" (Interview with Construction Manager B1). Reference has already been made to management's 'instructional' style. It is remarkable that a large construction project can be administered and completed with, aside from the drawings and documents used to mark up designs, only routine use of written records and instructions. Hendrickson (2008) describes the mechanisms for exchanging information in the process of project management as “fairly primitive”. The information flows described in this research rely primarily on talking, written reports and specifications and drawings.

Bowden (2004, p.12), concludes that the lack of feedback associated with traditional communication contributes to three principal shortcomings; message distortion, gate-keeping and information over-load. Information over-load arises when information is presented in a fixed format (a hard copy of the printed page), which requires the reader to spend time scanning the document to search for a relevant passage, file, or sequence of pages. Chen and Kamara (2008b, p.4), even before the widespread of advent of smartphones, saw the “limitation of paper-based files” as a “major constraint in on-site information communication and exchange”. Real time computerised information facilitates two-way communication in the form of instant feedback in a way that paper-based systems do not.

Son et al (2012) argue that by using the latest smartphones to capture and transmit information, mobile computing will help eliminate the types of errors and delays associated with manual approaches. As smartphone affordances have developed, the literature published in the last five years has expressed greater confidence in assessments of the feasibility of on-site mobile computing, because the almost universal ownership of smartphones has acquainted construction sector workers at all levels with the scope to manage and retrieve information via digital means (Pierce et al., 2011). Evidence of this appeared in case A, in which the interviewees indicated that they used “WhatsApp” when deciding to use an image to illustrate a point; however, there is no precedent for building a routine store of evidential photographic information. Photographs are only used as explanatory evidence in situations where there are problems on-site. In addition, B2 uses an email App on his smartphone to check to receive and send short emails when on-site. This counters Sidawi's (2012 p110) prediction that construction personnel are unlikely to use mobile systems aside from mobile phones to make voice calls.

7.4. Key Information Requirements

This section details the information needed by site based personnel based on the findings from the questionnaire, interviews and previous literature. Project managers were asked who selected the on-site roles, responsibilities and processes of information flow. Their answers were clear: them. The project managers explained that they had authority to distribute or withhold responsibilities and roles from their project staff. Their answer revealed that their position gives them influence over the lives of others, and makes them figures who are both respected and occasionally feared. This description of the project manager's role is consistent with a traditional construction organisation run along hierarchical lines. Their role in assigning or withdrawing responsibilities from other project workers reinforces their own role as the primary information gatekeeper, through whom all information flows. They then share information when and with whom they choose. According to Maki and Kerosuo (2015), construction-site managers are seen as "omnipresent paternal figures in full control of all situations on-site, in both foreseen and unforeseen situations".

The site engineer, explained, that it was essential to inform the project manager about "each and everything on-site because he has to take a direction either bad or good". For example, if a worker completes a task early he contacts the project manager "to assign new work for him". His unquestioned authority underlines the limitations of what is an overly centralised managerial hierarchy in which leaders lead, and followers follow, and consequently initiative is lacking. The project managers (A and C) are stated "we would not allow the site engineer to contact the storage directly. Instead, a paper request for materials is passed laboriously through a chain of command, for example, from the site-engineer to the project manager for evaluation and approval, then goes to storage".

As explained paper-based methods (which include printed 'daily reports') and mobile phones are used to distribute and transfer information on-site. Mistakes and inaccurate recording of data are key problems associated with using a paper based system in on-site conditions, or when recording events in real time and storing and filing photos and written records separately on data files. Arguably, using the latter method, errors can be tracked and observed more readily. Records stored on a paper based system, which does not centrally store data, are more likely to be lost, and this will increase delays (Arnorsson 2012 p19). Such problems cause tension and increase anxiety.

Chen (2008) highlights a recurring theme of this study, the strategic weakness inherent to order-less and unplanned traditional communication and information storage systems. This weakness is associated with the absence of a centralised repository for all project data. The ramifications of not having a centralised repository of project data extend beyond the failure of a paper information storage system, to an inability to provide personnel who are new to a project with instant access to the methods and solutions applied by previous contractors to resolve problems. This traditional approach de-motivates all personnel from keeping and sharing information about project progress and discourages a collaborative approach to sharing problems and solutions. Nourbakhsh et al. (2012a) noted that if such a repository existed, it could be used as a "form of communication between the project participants" and be used for "the integration of project information" (Nourbakhsh et al, 2012a, p.475). According to Dave et al. (2010), this problem has remained unresolved because "information systems are still disintegrated" (Chen 2008; Dave et al, 2010; Nourbakhsh et al., 2012a, p.475).

The difficulty of locating historic data can increase the number of delays. A1 anticipated that the introduction of an on-site digital system would conserve "mental effort" and improve efficiency by eliminating non-value adding activities, capturing information only once at the source and structuring collected data. The adoption of a mobile IT system is often represented as a means to transfer information and knowledge stored in a paper system to digital storage. However, a more accurate representation would be to transform a system based on "memory, experience and word of mouth" (Styhre et al., 2006), into a system that uses digital file sharing to build a permanent memory bank. Such a system would contribute to future projects by effectively creating and storing a pool of working knowledge, building a digital repository of learning. It would also make it possible to set up reusable templates and work procedures for repeated use.

The digital sharing of information would allow engineers to be less reliant on project managers' vocal commands, allowing them to follow structured task checklists set-out in shared files as working guidelines. By sharing information digitally, managers can also adhere to a plan of work that generates an historical record, showing when all tasks due for completion have been accomplished. This would be a change from the traditional practice of reporting to the project manager before even the smallest task can be considered finished. In a context where the project manager "is always on the phone" or "does not answer the phone because he is busy in a meeting" sharing information in this way would give other managers more initiative and reduce the stress on the project manager.

The autocratic management style adopted by project manager (C1) and Site supervisor (A1) helped the researcher to establish the types of information exchanged on-site, in order to understand the information requirements of site based engineers. This involved determining which document types site-based workers most want to access, so that these could be sent and received daily in the field. On-site information needs are intrinsically linked to the tasks being performed in the course of an operative's work. In Table 7-1, the information types related to the site engineer's perspective are documented though interviews and observations, and linked to the questionnaire findings, which provided similar results.

Table 7-1: The information requirements of site engineers and managers

Interviews data				Questionnaire Ranking	Communication Tool (Qualitative)	
Received	**Access**	**Send**	**Required information**		**Voice calls**	**Paper based**
	X		Drawings	1		X
	X		Specification	2		X
	X	X	Quality inspections request	3	X	X
X		X	Task allocation	5	X	
X	X	X	Request for information	6	X	
	X	X	Monitoring health and safety	8	X	
X	X	X	Monitoring progress	10	X	
X		X	Material and equipment Requests	11	X	X
		X	Daily report	12		X
X		X	Work directory	13	X	
X	X	X	Delay recording	17	X	
	X		Activities duration	19		X
X	X	X	Site diaries	22	X	X
	X		Work package information	23		X
	X		Subcontractor information	25		X

The similarities between the questionnaire data, the interview data, and the researcher's observations show that the last seven stages, from the daily report to sharing the subcontractor information, are less important from the site engineer's perspective; this is because, the daily report is submitted to the project manager at the end of the day. The work directory, activities duration, site diaries and work package information are organised by the project manager, sometimes at the beginning or middle of the day. Delay recording usually arises because of materials' and equipment being delivered late, or when activities clash. The final position refers to subcontractor information. As the government has restricted the involvement of subcontractors, big projects are now allocated to top level contractors only. Therefore, subcontractors are no longer allowed to construct a part of a project on behalf of the contractor.

Thus far, in the area of mobile computing some researchers have used applications practically to access specific project information. For example; site monitoring, task management, and real-time information sharing (using CCTV cameras) (Kim et al, 2013); design drawings and BIM modelling (Bringardner and Dasher, 2011); Augmented Reality and BIM (Wang et al, 2012); recording on-site progress (Garcia et al, 2014); progress monitoring, BIM 3D viewer, defect management and compliance testing (Davies and Harty, 2013); schedule updates, daily report, reporting violations, changing orders, report QC/QA problems, progress photo, accident reporting, report inspection results, productivity information, site inspections, variation order, delay recording, and design intent and clarification (Nourbakhsh et al., 2012a).

7.5. Key Challenges Facing Mobile Computing

This section discusses the findings and their relevance to the subjective understanding of challenges when seeking to provide timely and relevant information to site-based construction workers using literature, interviews and questionnaire. The literature revealed 23 challenging items that can be divided into two theoretical factors. To interpret the questionnaire, factor analysis (varimax rotation) was used to allow for items to be loaded according to corresponding factors. These items fall into four categories. Challenges related to management, technology, usability, and culture. These findings helped to assist the interviewees, to structure their thoughts, and to facilitate the extraction of themes from the views and opinions they expressed. Following the interviewees it was possible to rank the factors as follows: management, usability, technology and cultural.

7.5.1. Management Challenges

This factor was described as the most important item in this research, as indicated by the interviewees. It was also in the top three items on the questionnaire responses, according to the ranking (SI) for management.

Table 7-2: The challenges related to the management factor

Item	Interview Rank	Questionnaire Ranking	
		SI	Rank
U. The effect of top management support on the uptake of mobile computing	**1**	76.03%	**4**
R. The effect of existing management practices that reluctant to change when implementing mobile	**2**	79.72%	**1**
T. The effect of users' attitude on the acceptance of mobile computing	**3**	70.35%	**6**
V. The users' work requirements affect the adoption of mobile computing	**4**	77.87%	**3**
S. The availability of training support on the uptake of mobile computing	**5**	78.87%	**2**
W. The effect of staff proficiency in IT skills on mobile computing	**6**	74.61%	**5**

7.5.1.1. Top Management Support

This poses the greatest challenge. It has two fundamental connotations; financial and attitudinal. When considering how managerial culture limits IT implementation, Davies (2008) highlighted the perennial barriers of limited time and money available for investment in IT. Regarding planning for investment in IT, from the management perspective, the difficulty identifying and assessing the cost benefits of investing in IT was been discussed in (Section 3.5.4). The majority of research in this area, with the notable exception of Davies and Harty (2013), has emphasised the importance of management's strategic vision to the success of mobile computing. In addition, Son et al.

(2012) indicate it as a pivotal factor. With management support, mobile computing could make a notable contribution to speeding up and streamlining work processes. The overall perception is that 'builders' as a group are not computer users, although with appropriate support adoption can be encouraged.

7.5.1.2. Existing Management Practices

The effect of existing management practices was allocated second place by the interviewees, and in the questionnaire was ranked as a top item. The challenges created by the management process and system refer broadly to attitudinal issues relating to management structure, styles and relationships. It is commonly accepted that an individual's role in any organisation will determine their perspective and have a bearing on how they see their role and the roles of others. The effect of existing management practices on utilising mobile computing will need to accommodate management style in order to be adopted by construction personnel.

The evidence from this research suggests the work practices, relationships and managerial structure of the Saudi construction-site restrict collaboration. We have observed how tasks and information are managed downwards through the organisational hierarchy, which is built around tightly defined job descriptions and roles. In an over-centralised and hierarchical organisation, management personnel who might have exploited their positions to manipulate information flows will be anxious that increased information sharing could diminish their influence. This anxiety could act as a barrier to the uptake of an ICT culture. On-site middle management, accustomed to exercising their authority by command rather than collaboration, would have to accept that they cannot rely on their authority within the hierarchy, particularly if that authority is linked to family ties rather than ability. The transparency of mobile computing processes would call upon users to 'earn' their authority; instead of having it bestowed upon them. This would then serve to earn them the recognition of their peers for their efficient performance, knowledge and expertise, and merited promotion within the organisation

(Dainty et al., 2006, p.209).

It can be difficult for workers at the lower tiers of an organisation to contribute to policy decisions, or even to gain access to information concerning changes and developments taking place within a project. A site engineer (C3), when asked about the barriers to using mobile digital technology, responded that site engineers are “junior staff” and therefore “cannot decide”. Implicit in his response was the belief that his opinion is not valued, and he therefore offered little consideration to the matter. If he finds that something is wrong or some information is missing, the “first thing” he does is inform the project manager to “get guidance” or so that the project manager can communicate with whoever is responsible.

Extending mobile computing would open the lines of communication between management and workforce. Initiating shared access would also encourage collaboration, enabling engineers to record health and safety issues, or difficulties with job completion. Collaborative computing arguably has the capacity to break down junior staff’s passivity in the face of tightly defined roles and responsibilities; or, to put it another way, expand horizontal communication and overcome the information blockage associated with a single gatekeeper of information. Extending project communication can increase trust (and thereby increase employee loyalty and productivity).

Management in turn can also communicate their concerns, which should win employees’ cooperation and compliance (Vredenburgh, 2002; Fang et al., 2004; Abudayyeh et al., 2006). The problem is a lack of trust arises from ownership of the competence to perform specific tasks. A site manager (B2) will be sensitive to on-site status hierarchies when passing on, or seeking out information. If site engineers (B3 & B4) were to bypass the project manager they fear, he would “get angry” because he was not informed first and would then ask: why are you bypassing me? This point was also made by C2 as an example of management behaviour.

One site supervisor (C2) was unhappy about the restricted access to departments outside his specialised area. He explained that project managers guard their power and responsibilities. The site supervisor (C2) refers to project managers as individuals who have “to know and control everything” and “waste his time” by seeking to remain in full control of all situations on-site. The perception that the project manager jealously guards his authority inhibits collaboration and can build resentment. The site supervisor (C2) provided the example of a site engineer accusing his project manager of “taking pride”. An important aspect of working relationships is winning recognition for work done. When a site engineer has done a “fantastic job”, he believes his project manager will fail to acknowledge his efforts the way he should, and will instead claim the success for himself. The transparency and collaboration built into mobile computing systems would restrict opportunities for managers to indulge in such divisive behaviours.

The deference shown to leaders in positions of responsibility reflects not only their organisational position; but also the outcomes of class connections and experience. There are two implications for rigid management structures planning to adopt IT innovations. Firstly, senior management might underestimate the value of investing in new technology. Secondly, all instructions have to be ‘complete’. In other words, because instructions will be followed to the letter, possible omissions are likely to go unnoticed, and ambiguities will not be questioned. For this reason, the absence of initiative is the price paid for demanding staff obedience. The difficulty of operating a managerial hierarchy in which leaders lead, and followers follow, is that tasks that are not specifically requested, are likely to remain incomplete. Therefore, in a communication network with a deferential workforce, relying primarily on speech to function effectively, all instructions need to be issued clearly and in full. In the case of large construction projects, this is asking too much of managers. Extending an on-site IT system to middle management would relieve managers of the responsibility of relying on memory to recall processes, and gradually alter management style from an instructional autocratic approach, to a more collaborative one.

Although these benefits and processes would be absorbed slowly, information sharing would gradually free subordinates to show more initiative by enabling access to pre-planned work instructions. It would also free subordinates from having to always pass information through a hierarchical top down information chain. It would open up opportunities for innovative responses from assistant managers. In the current system, if something is not requested directly, it may not happen. Extending the lines of responsibility to on-site engineers might prove challenging in a system based on the traditional values of with respect and seniority, but to do so would relieve senior managers' workloads.

The evidence shows that senior site managers, including project managers, do not use time productively, and occupy themselves overly dealing with secondary issues. Maylor (2010) cites a study of American managers with no time management training, observing that 49 per cent of their time is spent on "tasks that could be done by their secretaries", and 43 per cent of their time is spent on tasks that could be delegated to colleagues (Maylor, 2010, p.270). Hegazy and Abdel-Monem (2012, p.130) estimate that "30–50 per cent of field supervisors' time is spent recording and analysing field data". Research by Styhre (2006) determined that site managers spend up to 80–90 per cent of their workday doing office work. The remainder of their time is spent talking to workers on-site, and working out on-site problems that arise in response to unexpected situations (Maki and Kerosuo, 2015 p165).

The evidence is provided in an interview with Site Manager (B2), in which he stated that 50% of his time is spent on-site, while the other half is spent in the site office, completing work and writing reports supporting previous research. In addition, site supervisor (A1) and Construction manager (B1), when asked how often they visited the site, answered "first thing every morning", after which they base themselves in the office for most of the working day. The frequency of site visits also reportedly depends on working rhythm and the pressure of work, although typically site visits are twice daily.

From the interviews with managers, a pattern of poor time management and an unwillingness to delegate emerges. Sharing a communication system between several on-site engineers can help alter poor management practices. The project manager is described as someone who has "to know and control everything" and "wastes time" by remaining in full control of all situations on-site. We have seen that (A1) (B1) and (C1) are often too busy to answer the phone. Requiring one person to consider "all the issues involved on a project" is impractical at best (Maylor, 2010, p.270). Mobile computing could push the project manager and his colleagues towards procedural and attitudinal modifications of present practice; for example, gradually changing the unwritten protocol that all information must be relayed through a single point of communication, in the person of the project manager.

The example of a Danish project manager, who allowed his craftsmen to keep working even though he suspected the quality of their work, would have to be revisited to allow alterations to the design (Arnorsson, 2012); we have also seen evidence of pressure being placed on the site manager, who was trying to coordinate the construction process. Executive Manager (A1) described his responsibility as "keeping engineers focused on their goals". He explained he is "trying to save them from headaches and confusion to save their time". His use of voice phone calls is reactive, not proactive. It is a communication tool, not a tool for storing and retrieving information.

Phone calls are used to solve problems, rather than to anticipate and prevent them. The mobile phone is not part of a shared and structured information sharing and retrieval system. It is a fire-fighting, not a fire prevention device. A1 and B1's shared priority is problem solving and getting things done. They use their mobile phones to fulfil demand immediately, issue orders, confirm progress, etc., although there is no record of the details of the exchange. However, these mobile phones are less suited to information exchange. The important point is that information exchange is asynchronous, passed on in a linear fashion, and not retained or recorded in an accessible information repository. The project manager initiates contact from the top down, and subordinates respond. The use of an IT system would encourage horizontal communication in a proactive fashion, with a likely attendant increase in efficiency and productivity.

7.5.1.3. Acceptance Attitude

The effect of users' attitudes on the acceptance of mobile computing was placed in third place according to the interviewees, but 6th in the questionnaires. It was not possible to interview very senior management, which possibly explains the apparent high reluctance of staff to use technology. All the interviewees showed positivity and acceptance towards mobile computing, because of its potential. A1 indicated that barriers were mentioned by staff, but not the younger members of staff. This confirms Moran's (2012) finding that "younger construction management" personnel appeared to use IT "more enthusiastically and effectively than older users" (Moran, 2012, p.148). However, the widespread use of mobile technologies such as smartphones and tablets transformed people's view of acceptance.

Son et al. (2012, p.81) indicated that users' attitudes towards the acceptance of mobile computing will be influenced by their utility, i.e. how well do they do the job. Also, Arnorsson (2012, p.43) found that acceptance is influenced by perceptions of user friendliness, i.e. how easy they are to use. While interviewees enthused about a new technology that would make their work easier without necessarily increasing profits, management bear the responsibility of securing a return on investment with little historical precedent to support their decisions. Middle-management staff considered that

IT innovation may be impeded by the uncertainties and resentment arising from a basic conflict in management systems, between, on the one hand a hierarchical management structure, and on the other, the interpersonal and inter-group collaborative communication processes required to implement on-site mobile computing.

7.5.1.4. Work Requirements

Users' work requirements were ranked fourth out of the six points. B2 and C1 were concerned about this point. A system is only as good as the information it contains, which is reliant on how it is pre-programmed and structured. The project database must be set up by a project administrator, who must pre-configure the data in a consistent and structured fashion, so that relevant fields are pre-populated. However, we have seen from the cases that no precedent exists in a system based on "memory, experience and word of mouth" for designing and creating a project database structured around checklists and templates. A company IT administrator must configure and format files so that on-site information can be entered and stored by a selected number of engineers to give structure to, and share on-site processes.

Wikforss and Löfgren (2007, p.341) interviewed "users of web based project networks". Their study found a mismatch between the intended purposes of web based project networks and the use of such systems in practice. Users reported that project networks "wasted time and were overly complicated" (Wikforss & Löfgren, 2007). It was apparently difficult to upload and structure documents, moreover, it was difficult to find information and time consuming to log on, search for and open documents. Wikforss and Löfgren (2007) conclude that project networks were not used as "active, dynamic communication networks but as passive, static archives" (Wikforss & Löfgren, 2007, p.341). Consequently, the web based IT network was primarily used as a means of document storage, as it did not support the intensive communication needed for problem-solving and decision-making processes in the construction industry. Instead, communication was conducted through other channels, as information was more likely to be distributed in “real time”, via informal channels, using e-mail, SMS messaging and telephone calls. The problem that arose was that this type of communication behaviour provides no possibility of ensuring the overall understanding and degree of coordination that a large project requires (Wikforss & Löfgren, 2007, p.342).

User involvement in the technical development and implementation of IT communication tools plays an important role in achieving their long term success (Wikforss & Löfgren, 2007, p.344). Peansupap and Walker (2005, p.202) suggest that open discussion within a construction company is an “important variable supporting ICT diffusion”. The importance of an open environment is that it encourages suggestions for improving and adapting unfamiliar IT use. Open discussion helps managers understand the initial problems experienced by those operating IT applications better, because it encourages the articulation of strategies to confront and remove potential deficiencies and allows suggestions for improvement (Peansupap & Walker, 2005, p.202). If an organisation’s values and management structure encourage open discussion, this helps the reporting of systematic difficulties, which would make it more efficient, increase acceptance and improve productivity.

The digital representation of construction information allows its presentation in various formats, including graphics, imagery, text, written, and verbal forms. Chen and Kamara (2011) state that the “format of construction information has a major impact on the output method of the mobile computer”. However, the mobile phone now delivers all these formats. They argue that the “storage capability of the mobile device should be able to store the necessary information files”; as Cloud Computing has largely removed the issue of file size and file storage.

Chen and Kamara’s (2008) discussion of the role of “information flow” is symptomatic of research that pre-dates the enhanced capacities of the smartphone in conjunction with

Cloud software. ‘Information flow’ 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 system or employee” (Chen and Kamara, 2008). Although Cloud Computing has made elements of the conceptual framework redundant, information flow is worthy of comment, because, by choosing a single individual to transfer data from the construction-site to an office based employee, Garcia Garcia et al.’s (2014) Construction Progress Control system applies a unidirectional asynchronous information flow, limited to the collection and transfer of site data to an offsite PC. Because there is only one recipient and one sender of the data, it would more properly be described as an information retrieval tool, rather than an information sharing tool.

Using Tablets, Cloud Computing and just a few App’s, Bringardner and Dasher (2011) describe Project Information Clouds (PICs) as a “simple way to store access and manage project information (drawings, specs and other project docs) in the cloud” which is accessible from tablets and desktops; more easily updated; and is always relevant (Bringardner & Dasher, 2011, p.2). They describe the system as (much) lighter, which is unsurprising, because it hosts 16,099 drawings, which would be printed as hard copies using traditional methods. These drawings are synched to 31 iPads. They describe the system as cheaper, because all 16,099 documents are available offline and online, and therefore need not be printed.

7.5.1.5. Training support

The availability of training support on the uptake of mobile computing were ranked in fifth place by the interviews and second by the questionnaire respondents. This reflects the importance of this factor, which plays a central role in the acceptance and usability of mobile computing, as Son et al. (2012, p.81) indicates. In a UK Commission report (2013) into technology and skills in the construction industry, emerging technologies are perceived to be high-risk in some cases, as they are “largely regarded as untried and untested, so it can be difficult to raise finance for projects” (Vokes & Brennan, 2013, p.52).

The overall perception is that ‘builders’ as a group are not computer users, although adoption can be encouraged with appropriate support. This took the form of formal training, publication of self-help guides and one-to-one support and coaching. ‘Training’ was not a one-off event, ongoing support was needed not only to assist but also to ‘bed-in’ the use of the technology (Davies and Harty, 2013, p.20). A focused and user friendly system, with a narrow scope and a clearly defined aim to share and retrieve information would suit the Saudi context. According to Nourbakhsh (2012b), the technical solutions for recording and sharing information are most likely to involve smartphones, tablets and Cloud Computing (Nourbakhsh 2012b p461). Garcia Garcia et al. (2014, p.95) stated that smartphones and tablets, when used correctly, could prove useful tools for project managers, engineers, architects, and subcontractors. Although, Anumba and Wang (2012) indicated that training and learning is essential, as mobile digital technologies are increasingly widespread this requirement lessens.

7.5.1.6. Repository of IT skills

Staff proficiency and IT skills came in the five place on the questionnaire and in last place in the interviews. B1 and B3 were concerned about the inadequate computing skills of staff members. However, the available training support, as C3 and A2 indicated will increase shared knowledge and the learning resources required by staff. However, the interview responses tell us that site personnel have the capability to operate mobile devices. Smartphones are being purchased in consistently high volumes every year, and an exploratory study of mobile computing trends in Saudi Arabia reports that mobile phone subscriptions reached 53 million in 2013 (a population penetration rate of 181.6%) and that users upload Apps facilitating “seamless and instant access to data anytime/anywhere” (Alotaibi & Mohammad Ibn, 2015).

Staff skills, specifically in terms of their ability to use technology, and the availability of training support were considered the two least important management related challenges. Although it is envisaged that only a handful of middle-management professionals would use the mobile technology, to operate mobile computing effectively, all staff would need to be able to understand how it is being used to effect on work-practices, to respond to the reports it generates, and cooperate in modifying work-practice by taking a more collaborative approach.

7.5.2. Usability Challenges

This factor came in second place in terms of importance. It refers to items related to the functionality of mobile devices as indicated by the interviewees, and it was found from the questionnaire that the items fall in the lower half in the (SI) ranking.

Table 7-3: Challenges related to usability factor

Item	Interview Rank	Questionnaire Ranking	
		SI	Rank
I. The effect of the complexity of mobile application on adopting mobile computing	**1**	66.38%	**7**
F. The data entry and display approaches effect adopting mobile computing	**2**	71.63%	**4**
L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device	**3**	71.77%	**3**
K. The portability (size and weight) of the device effect adopting mobile device	**4**	69.08%	**6**
J. The diversity of terminology and semantics among project members' effects the mobile adoption	**5**	76.03%	**2**
Q. The diversity of project members' languages effects the mobile adoption	**6**	70.78%	**5**
G. The effect of the device's screen size on which data are	**7**	77.73%	**1**

displayed			

7.5.2.1. The complexity of mobile application

The main usability challenge was the perceived complexity of any proposed mobile application. The majority of interviewees stipulated that any system should be easy to use. A simple file sharing system would aid the separate planning and recording of each specialist group's work within a project. A1 requested it to be easy to use, and should be configured around a single application that holds all the required information for exchange. This report from interviewees confirms the findings of many scholars that concerns centre on possible complexity (Son et al, 2012; Bowden, 2005; Kim et al, 2013; & Davies and Harty, 2013). Arnorsson (2012) specifies that an IT system for on-site construction must be "user friendly, robust, efficient in communication and must not be time-consuming to use".

7.5.2.2. Input and Output Methods

This factor ranked in 4^{th} place according to the questionnaire responses, but was ranked in second place by the interviewees. The majority of interviewees especially site engineers, indicated that fast and easy access to information via a device is essential. This point determined the success or failure of the utilisation of mobile computing. While data input is more critical, as the site engineers indicated that a lengthy data entry process might irritate them. They expressed inputs by taking pictures with the ability to highlight and write small notes. In addition, they found the use of tick boxes and multiple choice options were most effective for inserting data quickly and easily.

Input and output methods are important, as they have a direct impact on the usability of the devices on which data is represented and entered. With the rapid development of mobile devices, data input methods, including keyboards, touch screens, cameras for picture capture, video recorders, etc. and data output, which relies on the construction information format and mobile capabilities can generally be displayed in two forms: "the screen for the information formats of graphic, text, image, and speaker for verbal communication" (Chen and Kamara, 2011). The latest generation of smart-phones support "complex multi-touch input, gesture-based interaction, enhanced connectivity, and many dedicated special purpose applications" (Pierce et al., 2011).

7.5.2.3. Site Environmental Conditions

Construction conditions (such as temperature, humidity, and dust) ranked 3rd among questionnaire items. This factor was also ranked 3rd place by the interviewees. The interviewees were forgiving of the physical limitations inherent to the devices' technological constraints, but were frustrated by flaws, which were exacerbated by construction conditions. In this context, B4 stated that using the laptop in direct sunlight blurs the screen. B2 explained he was "wasting (his) time searching for papers on a laptop" when sunlight made the screen unreadable, he preferred to go back to the office to "access information faster". B2 said he "keeps his mobile phone in his pocket, but in the hot weather, it becomes so hot that he cannot put it to his ear". This confirms Assaf and Al-Hejji's (2006) comment that the hot weather in Saudi Arabia affects construction workers' performance and the execution of their duties.

Regarding mobile computing, Saidi et al. (2002) also referred to the potential limitations to its used caused by the harsh environment on construction-sites. Indeed, half of Bowden's (2005) survey respondents also questioned whether hand-held computers could be used on-site, asking if they would be able to withstand the environmental conditions. Similarly, smartphone use may be constrained by its unsuitability for the construction-site environment (Pierce et al., 2011). Kim et al. (2013) cite the impact of data input and output methods on the usability of devices, and as a limitation of their use at construction-sites, where efficient and effective information input can be affected by difficult conditions.

7.5.2.4. Portability of the Mobile Device

The size and weight of mobile devices was ranked 6th among the questionnaire and fourth by the interviewees in terms of usability challenges. When the interviewees were asked what would be a suitable device, A1, A3, B2 and C1 chose a tablet because of its larger size. The researcher argues that A1 and C1 chose a tablet because they spend most of their time in the site office. A2, C2, C3, B1, B3 and B4 expressed a preference for large smartphones. B1 and B4 chose these devices because of their relatively large screen size, and the fact that they allowed the option of making voice calls unlike a tablet. B3 and B4 highlighted another factor, which was that the device should be of a small size so that it is portable and easy to protect. They indicated that a tablet is too large to carry on a construction-site; citing as an example, that even when carrying paper drawings around the site for an hour or more they feel nervous.

A 2002 study by Bowden and Thorpe (2002) asked seventeen construction workers to assess the portability, screen clarity, appearance, and ease of data entry on portable devices. Dainty et al, (2006, p.204) stated that although the operational shortcomings exposed by such studies have been superseded by advances in hardware, it is noteworthy that this thirteen year old study found site-based staff were prepared to use devices to communicate with their teams. Chen (2008) refers to the obvious and unavoidable risk of loss or damage affecting such devices. The possibility raised was that break-down, or impairment of a device due to damage, could result in “all the work that had been carried out since the last synchronisation” being lost. Thus, tablets seem to be a viable option, as they will reduce portability (scope for damage) and are large enough to ensure legibility for users who prefer a clearer screen.

7.5.2.5. Diversity of Terminology

This variable came in fifth place in the interviews and second in the questionnaire. This factor was not considered important by the interviewees, as all have Arabic as their first language, and the interviewees from Cases A and C come from the same country. The member of middle management interviewed did not consider semantics and technical jargon a problem when operating a mobile device, as the working group specialises in the possession of the knowledge. However, B2 indicated that even when sending emails and making calls in Arabic his "emails and voice calls are misunderstood, and so "they go to the site to check the problem in reality". Even when individuals speak the same language they encounter problems with the vocabulary and glossaries. For example, although Arabic is the first language in several countries, the modes of expression and semantics differ between them. Simply put, jargon and semantics can contribute to communication problems. Dainty et al. (2006) indicated that a lack of standardisation in terms of size, quality and commonality of meaning in the vocabularies used by project management experts mean that individuals define similar processes differently. Regarding mobile computing, the terminology and semantics used by mobile workers must be universally understood to avoid misunderstandings and confusion.

Rebolj and Magdi (2012, p.132 cited in Anumba & Wang (eds), 2012) observed that site staff were engaged in solving specific IT related problems on-site. In their "on-site interpersonal communication exchange", a "discordance between formal and informal information flows was noticed". In other words, specialist groups in possession of the knowledge and learning resources required to set up innovative technologies did not use the terms and vocabulary familiar to layman. Instead, they used unintelligible techno-speak in an "informal communication" style, to form ad hoc teams and effectively solve problems. Rebolj and Magdi's findings confirm that a specialist group in possession of the knowledge and learning resources required to implement innovative technologies (Hore & Thomas, 2011, p.2) would not share their information beyond a "certain level in the organizational hierarchy". Therefore, the information would remain unavailable "to most participants, despite "the necessity of fast and effective exchange of information" between involved parties (Rebolj & Magdi p.132 cited in Anumba & Wang (eds), 2012).

7.5.2.6. Multiple Languages

Including a facility to use the tool in multiple languages, came in 5th place in the questionnaire and sixth in the interviews. Language differences between site engineers can result in communication problems. Discordance between formal and informal information flows is evident. In three cases, there are more than 5 different nationalities working together on-site at the project level, thus, problems of ambiguity arise even during voice calls. The formal language used in Cases A and B is English and the informal language is Arabic. Interviewees from Case A and B indicated that they used English when producing reports and for communicating with non-Arabic speakers. Arabic, English and other languages are used on-site, bit the techno-speak jargon is in English, with the result that "information [can] not be received accurately". Time is lost because engineers must repeat the same information more than once, which "annoys" them and takes extra time and effort. A2 stressed that the language of any mobile computing system must be in Arabic. Whereas, B3 indicated that the system should be in multiple languages.

A feature of the multi-national (multi-cultural) workforce is its multilingual communication. Dainty et al (2006) stated that the fragmented structure, culture and technical nature of the construction industry led to the emergence of formal and informal language around processes and people. As long as contracting companies employ a diversity of nationalities, language is an issue. This creates misunderstandings, confusion or embarrasses employees.

This study found that all the members of middle management speak Arabic as their first language. As most of us read, think, and understand best in our native language, Arabic workers want to read reports in Arabic (Zendera, 2013). Therefore, having an IT system that uses an Arabic script and produces reports in Arabic would guarantee a clearer understanding of any digital IT project. The description of instructions, procedures, reports and file names would be immediately and unambiguously clear to those individuals reading them. B2 (Site Manager) sends email and makes calls in Arabic, and remarked that his “emails and voice calls are misunderstood” and so the tendency is to “go to the site to check the problem is real”. Communicating in Arabic encourages all participants, project managers and engineers to buy into the system. However, like any system, it is only as complete and as good as the programmer designing it (Zendera, 2013).

7.5.2.7. Screen Size

The screen size of the mobile ranked first in the questionnaire and was ranked in last place by the interviewees. When the interviewees were asked what they thought would be a suitable device, they decided based on screen size, because the size of the device was relatively the same as the screen. A1, A3, B2 and C1 chose the tablet because of its large screen size. A2, C2, C3, B1, B3 and B4 chose large smartphones. Smartphones comes in different screen sizes. B1 and B4 chose large smartphone because they have a relatively large screen size and the capacity for voice calls, which is not available with a tablet. A1 stated that tablet is an appropriate device because of its portability, screen size and screen resolution, although the smartphone is small.

The barriers to smart phone usage include irritation over using small screens, a feature was only considered problematic when it was necessary for engineers to read quickly and comprehend large amounts of information (Alotaibi et al., 2015; Pierce et al., 2011). Since this observation was made, tablets have become a viable alternative for users who require a compromise between portability and legibility, according to the tasks being performed. We have seen evidence of a reluctance to use mobiles to respond to emails or to compose documents. Barkhuus and Polichar (2010) ascribe this reluctance to the difficulty typing on phones, despite the availability of hard keyboards and word completion algorithms.

Barkhuus and Polichar (2010) acknowledge that the multifunctional mobile phone confounds historical notions of human-computer interaction in the sense that the design of a small interface was once considered a barrier to its use in a commercial work environment. However, the limitations of the relatively miniature interface have become less important as screen size has increased, and Apps have enhanced these devices' multi-functional characteristics and expanded their users' opportunity to add and remove functions in the workplace. Barkhuus and Polichar (2010) identify the mobile's unique characteristics as its ability to select and blend functionality in the workplace; seeing its ability to mix, match and interconnect individual apps as the key to the smart phone's future success in the workplace (Barkhuus & Polichar, 2010).

7.5.3. Technology Challenges

This factor was placed in third place in terms of importance. It relates to items associated with the technological components of mobile devices, as stated by the interviewees. It also emerged from the questionnaire that most of the items were positioned in the lower half in the (SI) ranking.

Table 7-4: Challenges related to the technology factor

Item	Interview Rank	Questionnaire Ranking	
		SI	Rank
A. The data security issue effect utilising mobile computing	**1**	72.62%	**3**
D. The availability of technical support on the uptake of mobile computing	**2**	67.66%	**5**
C. The Device performance that affect mobile adoption	**3**	74.18%	**2**
B. The effect of battery consumption on utilising of mobile device	**4**	70.78%	**4**
E. The effect of the device's screen clarity on presenting the project information	**5**	76.03%	**1**

H. The device capabilities that impact on the mobiles' utilisation	**6**	66.81%	**6**

7.5.3.1. Security of Information

Security of information was the primary concern raised in the interviews and questionnaire respondents placed this feature 3rd. The loss of direct physical control over data naturally creates concerns about security among those using technology, because they feel personally responsible for keeping it safe. B1 ranked the security of information fourth of 7 challenges. He explained security was important because "the company is responsible for information, such as drawings, that the government considers sensitive". Pierce et al. (2011) conclude that although security mechanisms are a significant barrier to wider use of smartphones for business, these can be overcome (Pierce et al., 2011).

In Davies and Harty's (2013) study, the Document Management System (DMS) was used to store, access, share and manage project information. This is an in-house system developed and maintained project document by the contractor. Alternatively, Bringardner and Dasher's (2011) study used the Cloud for storage. The Cloud is an alternative option for an external party wishing to control project data. According to Nourbakhsh et al. (2012b, p.461) and Fernando et al. (2013, p.103), mobile Cloud Computing helps overcome the resource limitations of mobile devices by providing a "seamless and rich functionality". It could also become the dominant model for mobile applications in the future (Fernando et al 2013 p 103). Fernando et al. (2013) argue that mobile Cloud Computing links the rising value of the market for cloud-based mobile applications, "worth $9.5 billion at 2014" (Fernando et al., 2013, p.97), to the increasing use of mobile computing in commercial settings. Implicit to the uploading of sensitive data to the cloud is the surrender of direct physical control over data. It is therefore imperative that an effective recovery insurance mechanism is provided to retrieve lost data in the case of technological failure, or other malfunction.

7.5.3.2. Technical Support

The availability of technical support was ranked as the 5th most significant issue in the questionnaire, and second in the interviews. All the interviewees insisted that the availability of a technical unit located at the project offices is important. They argued that such as unit would be integral to effectively maintaining the system and associated mobile devices on-site, by insuring the platform keeps running and fixing any faults. Technical support plays a vital role in problem resolution, and also includes practical aspects of user requirements, such as “specialized instruction, guidance, coaching, and consultation in using technology” (Son et al., 2012). User involvement in the technical development and implementation of IT communication tools plays an important role in achieving long term success (Wikforss and Löfgren, 2007, p.344). The relationship between the usability of mobile computing and technical support is equitable. The higher level technical support offered creates a higher probability of the successful adoption of mobile computing.

7.5.3.3. Device Performance

The device performance was ranked second in the questionnaire and third in the interview. Interviewees (A1, A2, B1 and B4) ranked it in fifth and sixth place, as they have a good knowledge of IT. Furthermore, the researcher observed they were using the latest smartphones. Despite the increasing usage of mobile computing, exploitation of its potential is complicated by problems such as “resource scarcity, frequent disconnections, finite energy and low connectivity and mobility” (Fernando et al., 2013, p.97). In addition, mobile devices are not as robust as desktop PCs and faults occur more frequently (Fernando et al., 2013, p.102).

Commonly used applications on construction-sites include sensors to get GPS readings to confirm the location of site work. These applications are high energy consuming and expensive, and require extensive processing, imaging and speech processing, such as the augmented reality used in Kim et al.’s (2013) proposed model, which demands high computational capabilities that restrict performance. Writing in 2013, Fernando et al. (2013, p.84) forecast that limitations in battery design make it "unlikely that these problems will be solved in the future" and that far from being "temporary technological deficiencies" the problems prevents the realisation of the full potential of mobile computing, which is "intrinsic to mobility".

7.5.3.4. Battery Consumption

Battery consumption of devices ranked fourth for both the interviews and the questionnaire. A1, A2, B1 and B4 were concerned about battery duration when performing on-site. Bowden's (2005) participants referred to the limited battery power of devices as an inconvenience which "could create reluctance to rely on the device", especially where staff are "working an 8-10 hour day". Data input and output methods also effect mobile battery life, observing that mobiles must be able to function over a long period of time to support the user when they are outdoors and engaged in site construction (Bowden, 2005; Kim et al., 2013).

7.5.3.5. Screen Clarity

Screen resolution and visibility were designated first in the questionnaire and fifth by the interviewees. B4 commented that when using a laptop in direct sunlight it can be difficult to see the screen. Chen (2008) indicated that data output is affected by screen visibility and resolution. Elsewhere, other scholars have highlighted this variable (Saidi et al., 2002; Bowden & Thorpe, 2002). However, these limitations have been largely overcome. Nowadays, mobile devices are developed and equipped with high definition (HD) screen resolution, which provides clearer visibility.

7.5.3.6. Device Capabilities

This variable ranked in the least significant challenge for the interviewees and questionnaire. A1, A2, B1 and B4 also ranked this as the least significant challenge, as they are confident that the technology available on the latest smartphones provides sufficient affordances. Bowden (2005) also identified the top ten processes perceived to offer the greatest potential for improvement in the use of mobile IT. She was writing in 2005, before Tablets, Smartphones, etc. came onto the market. Her conclusions are prescient, but are qualified by the technical limitations that existed at that time. For example, the participants reportedly disliked the smaller screens available then on mobile devices prior to 2005 for viewing and annotating drawings (Bowden, 2005, p.61). The latest generation of smart-phones support "complex multi-touch input, gesture-based interaction, enhanced connectivity, and many dedicated special purpose applications" (Pierce et al., 2011).

7.5.4. Cultural Challenges

This factor come in last place in terms of importance. It comprises items related to the culture of users of mobile devices, as stated by the interviewees. In addition, it was among the lowest two items in the (SI) ranking.

Table 7-5: The challenges related to the cultural factor

Item	Interview Results	Questionnaire Ranking	
	Total Rank	SI	Rank
M. The effect of high level entities in the project on the adoption of mobile computing	**1**	73.76%	**1**
N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.	**2**	73.05%	**2**
P. The effect of social influence on the user's adoption of mobile computing	**3**	63.97%	**3**
O. The level of education on the diversity of nationals (multicultural) effects mobile Implementation	**4**	62.84%	**4**

7.5.4.1. The High Level of Entities

The fragmented nature of operations in project work was judged the 1st of 4 issues recognised as posing challenges to the free flow of information by the interviewees and in the questionnaire. This fragmentation is complicated by the project-based nature of construction. That is, the teams are temporary, and on-site relationships are constantly changing, which complicates the building of trust and establishment of shared goals. Davies and Harty (2013) exposed the weaknesses implicit in generalisations when considering the role of IT driven projects in construction innovation. They challenged the generalised and unquestioned assumption that “firms are single, definable entities”, whereas the reality is that in “project-based firms in particular, project teams may have minimal contact with the firm's senior management” (Davies & Harty, 2013, p.16).

7.5.4.2. Work Habits

Work habits were designated second place in the interviews and the questionnaire. There was also evidence that an individual’s role in the construction hierarchy determines their perspective and has a bearing on how they perceive the role of others. In theory, the advantage of a hierarchical leadership structure is that it establishes a clear chain of command. We have seen evidence of how autocratic management styles “may get the task achieved, but often at the expense of the project team” (Maylor, 2010, p.38). This emphasis on end-results has produced a pyramid management structure, developed specifically to manage a disparate poorly educated workforce with the aim of getting the job done. It is “accepted as the most efficient way to produce results” and involves the issuance of top-down commands, in the expectation of obedience (Hooijberg & Broeckx in Hooijberg & Hunt (eds), 2007, p.52).

In addition, this research has found evidence of information gatekeepers who “jealously guard their knowledge of how the business operates”, taking credit when it has not been earned, and spreading blame beyond culpable individuals. Autocratic leadership styles result in low job satisfaction and low morale, because individuals devalue the emphasis on trust and face-to-face relationships, which the culture holds in high regard (Cerimagic & Smith, 2011, p.397). Considering the evidence from interviews and observations, in a situation where the roles and responsibilities of some members of management reflect an autocratic style, and where information flow is tightly controlled and manipulated for personal gain, the management processes and systems represent significant challenges to a consensual approach to implementing a collaborative system of working, based on sharing and cooperation.

There was also evidence offered by interviewee A1 on this subject. He indicated that the system should be flexible in order for companies to modify it according to their workflow (processes). A1 mentioned as an example, if we consider the two projects involved in constructing the company, we will find that this project differs from other projects in its management and Organisational Breakdown Structure. Each project has different characteristics, in accordance with a unique Organisational Breakdown Structure that establishes different responsibilities among staff. Project managers must focus on the development of senior managers' capabilities to re-order work, based on a reliance on word of mouth and face-to-face instruction, to establish a more structured and accountable system based on shared responsibility. This approach would encourage collaboration and eventually, create values based not only on cost savings, but also on improvements to the quality of work, creating a pool of IT knowledge upon which the company and industry could be build.

The current setup of management systems and processes are socially complex, but also unpredictable and autocratic. Project managers are often left to their own devices, coping with complexity 'saving headaches' without assistance from technology. They must develop new ways of thinking, which utilise technologies' capacity to plan, structure and standardise the complexity of 21st century projects. One of the important messages raised in this research is the need for Saudi construction companies to review their approaches to IT training, and to develop the knowledge and skills required by modern construction management. Site personnel are already familiar with the operations mobile phones and tablets can perform.

7.5.4.3. Social Influence

The effect of social influence on user's adoption of mobile computing was ranked third in the interview and questionnaire. An array of authors (Dainty et al, 2006; Nof et al, 2009; Chen and Kamara, 2011) assert that efficient construction is based on good communication. According to Anumba and Wang (2012), it is impossible to "divorce interpersonal and inter-group communication from the construction process" and it is in these communicative interactions between management and workers, between mixed multi-cultural and multi-lingual interests, that the success or failure of any project will be rooted. All these authors confirm that effective communication is essential to efficient and successful operation. A directional autocratic management style is employed, because managers believe it is effective for getting the job done in the structurally fragmented conditions of the Saudi construction industry.

The introduction of a digital communication and information sharing system will initially unsettle some interpersonal relationships. Some management personnel may feel that sharing information dilutes their power to control and instruct, whereas others may believe their status is questioned by a system that opens itself up to scrutiny by peers, and encourages less experienced colleagues, who previously relied on instruction, to show initiative. The degree to which the system calls on a refashioning of working relationships towards interpersonal collaboration would be a matter for negotiation, subject to the number of personnel involved and the extent to which a new system redirects information flows. New technology is more likely to be greeted positively if it is seen to be effective, is proven to reduce the stress associated with middle management's workload, and is seen to be efficient and easy to use. By providing such advantages it would incentivise the rebalancing of the interpersonal relationships between collaboration and instruction (Dainty et al., 2006, p.9).

7.5.4.4. Low Education

Both questionnaire respondents and interviewees ranked low level of education as the least important item. Similarly, among the usability challenges, multilingual challenges were rated 6^{th} of 7 options. As the interviewees all come from one region, language and educational issues create minimal variance in terms of the adoption of mobile computing. The researcher observed that contractor companies tend to employ middle-management personnel from a single country, such as in cases C and A, or from different countries in one region, as with case B.

In an age of technological revolution, prosperity depends on knowledge, in the form of a workforce that possesses the education and skills to acquire new knowledge and apply it to problem solving and innovation (Whitaker, 2009, p.31). Technological progress and the diffusion of technical innovations leads to increased productivity. Higher skill levels in the labour force, which is an outcome of improved educational levels, permits workers to use new technology and boosts productivity. The ability of any society to produce, adapt and commercialise knowledge is critical for its sustained economic growth. By 2003, the Saudi Human Development Report was acknowledging these technological challenges and the need to overcome them, by increasing “connectivity, to benefit from growing knowledge information and cultural exchange among nations” (Kingdom of Saudi Arabia, Human Development Report, 2003, p.9).

7.6. Summary

This chapter has discussed the communication tools currently in use in the KSA (Section 7.3) among site-based personnel, building on the findings from the questionnaire and interviews, as well as relevant literature. The tools used to communicate and pass information on to other project team members are: voice phone calls and paper-based media (letters/reports). In Section 7.4 this chapter highlighted the key information requirements of site-based personnel; this information is exchanged on daily basis, and can be supported by mobile technology.

Moreover, this chapter discussed key findings in relation to the subjective understanding of the challenges in providing timely and relevant information to site-based construction workers, drawing on literature (Chapters 2 and 3), interview data (Chapter 6) and questionnaire data (Chapter 5). The literature highlighted 23 challenging items. The questionnaire factor analysis (Section 5.4) was used to allocate items to four categories, which are: challenges related to management, challenges related to usability, technological and cultural challenges. Using a performance prism approach, these provide critical dimensions of the framework, which require further exploration. There are five items that, following the discussion, appear not to affect the implementation of mobile computing in Saudi Arabia. These variables are: screen size (Section 7.5.2.7), device capabilities (Section 7.5.3.6), low education (Section 7.5.4.4), social influence (Section 7.5.4.3) and the effect of staff IT proficiency (Section 7.5.1.6). However, the last three items may have a strong effect on the implementation of mobile computing in other countries. Finally, 18 items affect the implementation of mobile computing. They will be used to develop a strategic framework for implementation using Interpretive Structural Modelling (ISM), in the next chapter.

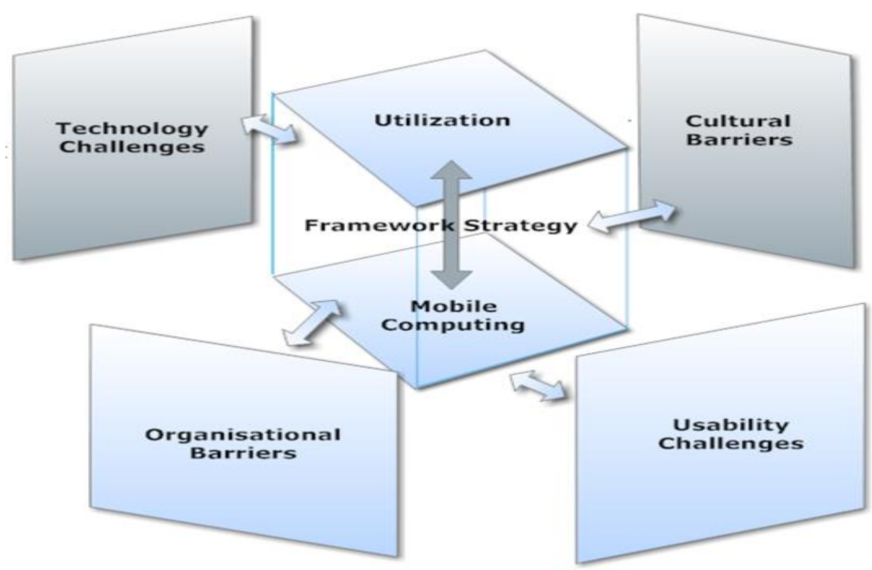


Figure 7-1: Four key dimensions of the framework strategy

Chapter 8: Framework Development and Validation

8.1. Introduction

The next stage after collection and discussion of the research findings is to test them. This chapter presents the framework development and the validation approaches employed to test the scope for the implementation of mobile computing in Saudi Arabia by evaluating the identified challenges. As explained previously, this research used a mixed-methods approach, gathering quantitative data “questionnaires” from 205 participants, and qualitative data “semi-structured interviews” from 10 site based personnel. In this chapter, the researcher reports on the results when applying the framework development and the validation methods “Interpretive Structural Modelling (ISM)” to analyse the findings from the qualitative data “focus group” (including 6 experienced project managers and site engineers) to validate the findings.

8.2. ISM Methodology

Interpretive Structural Modelling (ISM) is intended as a tool to identify the relationships between variables, leading to the definition of a problem or an issue (Warfield, 1974; Sage, 1977). The underlying assumption is that expert practical experience and knowhow is used to decompose a complex system into its component parts and to reconstruct a multilevel structural model (Warfield, 1976). Interpretive Structural Modelling is generally deployed to reveal “shared mental models”. These shared mental models are then used to compose a tentative theoretical framework because they encapsulate how individuals understand and explain the particular phenomenon being studied (Warfield, 1974).

Upon reviewing the mobile computing literature and the opinions of the interviewees, 18 important challenges were identified. The discussion was used to develop a relationship matrix, later used in the development of an ISM model. The main objective of this section is to rank the challenges, to determine the interaction between the identified challenges by the use of ISM. In addition, it is important to identify the variables from the focus group and to develop a Structural Self-Interaction Matrix (SSIM) to identify the relationship between each variable horizontally, so the ISM will be effective.

8.3. Development of the Implementation Model

In this research, the ISM-based approach is used to represent the relationship between the challenges that affect the implementation of mobile computing, to present them according to their drivers and effect on power. The following actions are characteristic of the ISM methodology (Charan et al., 2008):

1. Gather together an ISM implementation group. The chosen group should have sound knowledge, skills and backgrounds relevant to the study topic.
2. Identify and select the relevant variables. During this stage, variables affecting mobile computing are identified.
3. Develop a structural self-interaction matrix (SSIM). The knowledge and experience of the expert group is used to hypothesise relationships among the variables, and to build a matrix to illustrate the pairwise relationships between the variables of the system under consideration.
4. Determine the reachability matrix. Based on the SSIM, the reachability matrix is developed. The transitivity of the contextual relationships is a basic assumption made in ISM. If variable A is related to variable B and variable B is related to variable C, then variable A is necessarily related to variable C.
5. Decompose the "reach-ability matrix" into different levels. The reach-ability matrix is decomposed to create structural models. That is, a directed graph is drawn and all transitive links removed.

8.3.1. Structural Self-Interaction Matrix

The 18 items below effects the implementation of mobile computing that listed below in order to develop a strategic implantation model by the use of ISM.

Table 8-1: The Challenges Variables

No.	Items	Code
1	V. The user's' work requirements affect the adoption of mobile computing	**The user's' work requirements**
2	S. The availability of training support on the uptake of mobile computing	**Training support**
3	U. The effect of top management support on the uptake of mobile computing	**Top management support**
4	R. The effect of existing management practices that reluctant to change when implementing mobile	**The existing management practices**
5	T. The effect of users' attitude on the acceptance of mobile computing	**The users' attitude**
6	E. The effect of the device's screen clarity on presenting the project information	**Device's screen clarity**
7	A. The data security issue effect utilising mobile computing	**The data security**
8	C. The lack of an IT infrastructure that affect mobile adoption	**IT infrastructure**
9	D. The availability of technical support on the uptake of mobile computing	**Technical support**
10	B. The effect of battery consumption on utilising of mobile device	**Device battery consumption**
11	I. The effect of the technological complexity on adopting mobile computing	**The technological complexity**
12	L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device	**The site conditions**
13	K. The portability (size and weight) of the device effect adopting mobile device	**The device portability**
14	F. The data entry and display approaches effect adopting mobile computing	**The data entry and display**
15	Q. The diversity of project members' languages effects the mobile adoption	**Diversity of languages**
16	J. The diversity of terminology and semantics among project members' effects the mobile adoption	**Diversity of terminology**
17	N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.	**Work habits**
18	M. The effect of high level of entities in the project on the adoption of mobile computing	**High level of entities**

All possible pairs of challenges were selected above in Table (8-1) and the experts were requested to classify the relationship between two challenges items as either:

- V (item i will assist achieve item j); item 2 assists achieve item 4. This means that as “The availability of training support” rises the “The existing management practices” increases as well. Therefore, the relationship between item 2 and 4 is represented by “V” in the SSIM.
- A (item j will be achieved by item i); item 2 can be achieved by item 3, i.e. item 3, “Top management support”, assists achieve item 2, “The availability of training support”. Top management support would encourage the availability of training support. Therefore, the relationship between these items is represented by “A” in the SSIM.
- X (item i and j will assist achieve one another); item 1 and 10 assist achieve each other. Item 1, “The user's’ work requirements”, and item 10, “Device battery consumption”, assist achieve each other. Therefore, the relationship between these item is represented by “X” in the SSIM.
- O (item i and j are unrelated); no relationship exists between “Top management support” (item 3) and “Device battery consumption” (item 10) and therefore the relationship between these items is represented by “O” in the SSIM

This provides us a means by which order can be imposed on the complexities informing the variables (Jharkharia, Shankar, 2005; Singh, Shankar, Narain, Agarwal, 2003). The following explains the use of the symbols V, A, X and O in the SSIM (Table 8-2):

Table 8-2: Structural Self-Interaction Matrix (SSIM)

i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	X	O	A	O	O	O	O	O	O	X	X	O	O	V	O	A	A	O
2		X	A	V	X	O	O	X	X	V	V	V	O	X	V	V	V	X
3			X	V	V	O	X	X	V	O	X	O	O	O	O	O	V	O
4				X	O	O	O	O	A	O	O	O	O	O	O	O	X	X
5					X	A	A	A	A	A	A	A	A	A	A	A	A	A
6						X	O	O	O	X	O	A	A	O	O	O	O	O
7							X	X	A	O	X	O	O	A	O	O	O	O
8								X	X	O	O	O	O	O	O	O	O	O
9									X	V	V	A	O	O	A	O	O	O
10										X	O	X	X	X	O	O	O	O
11											X	O	O	A	A	A	O	A
12												X	O	V	O	O	O	O
13													X	X	O	O	O	O
14														X	A	A	A	O
15															X	X	V	V
16																X	V	V
17																	X	X
18																		X

Table 8-3: Structural Self-Interaction Matrix (Initial and Final)

i\j	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	X	O	A	O	O	O	O	O	O	X	X	O	O	V	O	A	A	O
2	O	X	A	V	X	O	O	X	X	V	V	V	O	X	V	V	V	X
3	V	V	X	V	V	O	X	X	V	O	X	O	O	O	O	O	V	O
4	O	A	A	X	O	O	O	O	A	O	O	O	O	O	O	O	X	X
5	O	X	A	O	X	A	A	A	A	A	A	A	A	A	A	A	A	A
6	O	O	O	O	V	X	O	O	O	X	O	A	A	O	O	O	O	O
7	O	O	X	O	V	O	X	X	A	O	X	O	O	A	O	O	O	O
8	O	X	X	O	V	O	X	X	X	O	O	O	O	O	O	O	O	O
9	O	X	A	V	V	O	V	X	X	V	V	A	O	O	A	O	O	O
10	X	A	O	O	V	X	O	O	A	X	O	X	X	X	O	O	O	O
11	X	A	X	O	V	O	X	O	A	O	X	O	O	A	A	A	O	A
12	O	A	O	O	V	V	O	O	V	X	O	X	O	V	O	O	O	O
13	O	O	O	O	V	V	O	O	O	X	O	O	X	X	O	O	O	O
14	A	X	O	O	V	O	V	O	O	X	V	A	X	X	A	A	A	O
15	O	A	O	O	V	O	O	O	V	O	V	O	O	V	X	X	V	V
16	V	A	O	O	V	O	O	O	O	O	V	O	O	V	X	X	V	V
17	V	A	A	X	V	O	O	O	O	O	O	O	O	V	A	A	X	X
18	O	X	O	X	V	O	O	O	O	O	V	O	O	O	A	A	X	X

8.3.2. Reachability Matrix

The Structural Self-Interaction Matrix (Initial and Final) is converted into a binary matrix (Table 8-4), called the initial reachability matrix by replacing 0 or 1 for the original codes, V, A, X and O. The guidelines for the replacement are as flow (Azevedo et al, 2013):

- If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix converts to 1 and the (j, i) entry converts 0.
- If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix converts to 0 and the (j, i) entry converts to 1.
- If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix converts to 1 and the (j, i) entry converts to 1.
- If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix converts to 0 and the (j, i) entry converts to 0.

Table 8-4: Initial Reachability Matrix

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
2	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**
3	**1**	**1**	**1**	**1**	**1**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
4	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**
5	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
7	**0**	**0**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
8	**0**	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
9	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
10	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
11	**1**	**0**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

12	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**
13	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
14	**0**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
15	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**
16	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**1**
17	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**1**
18	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**

The final reachability matrix is gained shown in (Table 8-5). This table, the driving and dependence powers of all items is presented. The driving power of a specific item is the whole number of items (with itself) that it might assist achieve. The dependence is the whole number of items that might assist achieving it. The driving power and dependence power are used in the MICMAC analysis (see Section 8.3.5), where the challenge items will be categorised into four groups, as autonomous, dependent, linkage and independent.

Table 8-5: Final Reachability Matrix

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**Driving power**
1	1	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	0	0	**4**
2	0	1	0	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	**13**
3	1	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	1	0	**10**
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	**3**
5	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
6	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	**3**
7	0	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	**5**
8	0	1	1	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	**6**
9	0	1	0	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	**8**
10	1	0	0	0	1	1	0	0	0	1	0	1	1	1	0	0	0	0	**7**
11	1	0	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	**5**

12	0	0	0	0	1	1	0	0	1	1	0	1	0	1	0	0	0	0	**6**
13	0	0	0	0	1	1	0	0	0	1	0	0	1	1	0	0	0	0	**5**
14	0	1	0	0	1	0	1	0	0	1	1	0	1	1	0	0	0	0	**7**
15	0	0	0	0	1	0	0	0	1	0	1	0	0	1	1	1	1	1	**8**
16	1	0	0	0	1	0	0	0	0	0	1	0	0	1	1	1	1	1	**8**
17	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	**6**
18	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0	0	1	1	**6**
Dependence power	**6**	**7**	**4**	**6**	**16**	**4**	**6**	**5**	**6**	**8**	**10**	**3**	**3**	**9**	**3**	**3**	**7**	**6**	

8.3.3. Factors' Levels

This section is the next step to partitions of the level. By using the reachability and antecedent set for each item is found from final reachability matrix (Table 8-5). Warfield (1974) indicated that the "reachability set" for a specific item contains of the item itself and the other items that it might assist achieve; also, he stated that "antecedent set" consists of the item itself and the other items that might assist in achieving it. Then, the intersection of these sets is resulting for the all items. The items that the reachability and the intersection sets are alike, is position in the top-level of the ISM hierarchy, as they will not assist achieve any other item above their own level. After the identification of the top-level element, it is removed from the other remaining items.

From Table 8-6 , it is perceived that "The users' attitude" (item 5) and "The existing management practices" (item 4) are found to be at level I. Therefore, it positioned at the top of the ISM model. This procedure is then repeated until the levels of all the items are found Table (8-7). The identified levels help in structuring the diagram and the final model of the ISM (Figure 8-1). The items, together with their reachability set, antecedent set, intersection set and levels, are presented in the Appendix.

Table 8-6: Partition of reachability matrix: interaction 1

Items Number	Reachability set	Antecedent set	Intersection	level
1	1, 10, 11, 14	1, 3, 10, 11, 16, 17	1, 10, 11	
2	2, 4, 5, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18	2, 3, 5, 8, 9, 14, 18	2, 5, 8, 9, 14, 18	
3	1, 2, 3, 4, 5, 7, 8, 9, 11, 17	3, 7, 8	3, 7, 8	
4	4, 17, 18	2, 3, 4, 9, 17, 18	4, 17, 18	**I**
5	2, 5	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18	2, 5	**I**
6	5, 6, 10	6, 10, 12, 13	6, 10	
7	3, 5, 7, 8, 11	3, 7, 8, 9, 11, 14	3, 7, 8, 11	
8	2, 3, 5, 7, 8, 9	2, 3, 7, 8, 9	2, 3, 7, 8, 9	
9	2, 4, 5, 7, 8, 9, 10, 11	2, 3, 8, 9, 12, 15	2, 8, 9	
10	1, 5, 6, 10, 12, 13, 14	1, 2, 6, 9, 10, 12, 13, 14	1, 6, 10, 12, 13, 14	
11	1, 3, 5, 7, 11	1, 2, 3, 7, 9, 11, 14, 15, 16, 18	1, 3, 7, 11	
12	5, 6, 9, 10, 12, 14	2, 10, 12	10, 12	
13	5, 6, 10, 13, 14	10, 13, 14	10, 13, 14	
14	2, 5, 7, 10, 11, 13, 14	1, 2, 10, 12, 13, 14, 15, 16, 17	2, 10, 13, 14	
15	5, 9, 11, 14, 15, 16, 17, 18	2, 15, 16	15, 16	
16	1, 5, 11, 14, 15, 16, 17, 18	2, 15, 16	15, 16	
17	1, 4, 5, 14, 17, 18	2, 3, 4, 15, 16, 17, 18	4, 17, 18	
18	2, 4, 5, 11, 17, 18	2, 4, 15, 16, 17, 18	2, 4, 17, 18	

It was found from (Table 8-7) that “top management support” was most the important item for the focus group as well as interviewees in the management factor and sixth out of twenty three items for the questionnaire’s participants. This was followed by “the availability of training support”, that, on the other hand, came fifth in the management factor when looking at the results from the interview. Moreover, “the diversity of project members’ languages” and “the diversity of terminology and semantics” came in third place as they are important to the focus group.

They was ranked as sixth and fifth in the in the usability factor in the interview. The least important items for the focus group were “the existing management practices” and “users’ attitude”. The focus group members indicated that mobile computing can accommodate any management structure. As well as the potentials of mobile computing are quite high which force the users’ attitude towards acceptance.

“The existing management practices” ranked in the second place in the management factor in the interview and the top level in the questionnaire. “Users’ attitude” was ranked seventeenth in the questionnaire and third place in the management factor in the interview. Once more, and in line with the other sections, there seem like to be consistency on the most important items and the least important item “Users’ attitude”; hence validation can be assumed.

Table 8-7: Item Levels

Level	Items Number	Items
1	4	R. The effect of existing management practices that reluctant to change when implementing mobile
	5	T. The effect of users' attitude on the acceptance of mobile computing
2	6	E. The effect of the device's screen clarity on presenting the project information
	7	A. The data security issue effect utilising mobile computing
	8	C. The lack of an IT infrastructure that affect mobile adoption
	10	B. The effect of battery consumption on utilising of mobile device
	11	I. The effect of the technological complexity on adopting mobile computing
3	9	D. The availability of technical support on the uptake of mobile computing
	13	K. The portability (size and weight) of the device effect adopting mobile device
	14	F. The data entry and display approaches effect adopting mobile computing
	18	M. The effect of high level of entities in the project on the adoption of mobile computing
4	12	L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device
	1	V. The user's' work requirements affect the adoption of mobile computing
5	17	N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.
6	15	Q. The diversity of project members' languages effects the mobile adoption
	16	J. The diversity of terminology and semantics among project members' effects the mobile adoption
7	2	S. The availability of training support on the uptake of mobile computing
8	3	U. The effect of top management support on the uptake of mobile computing

8.3.4. Building the ISM-based model (Digraph)

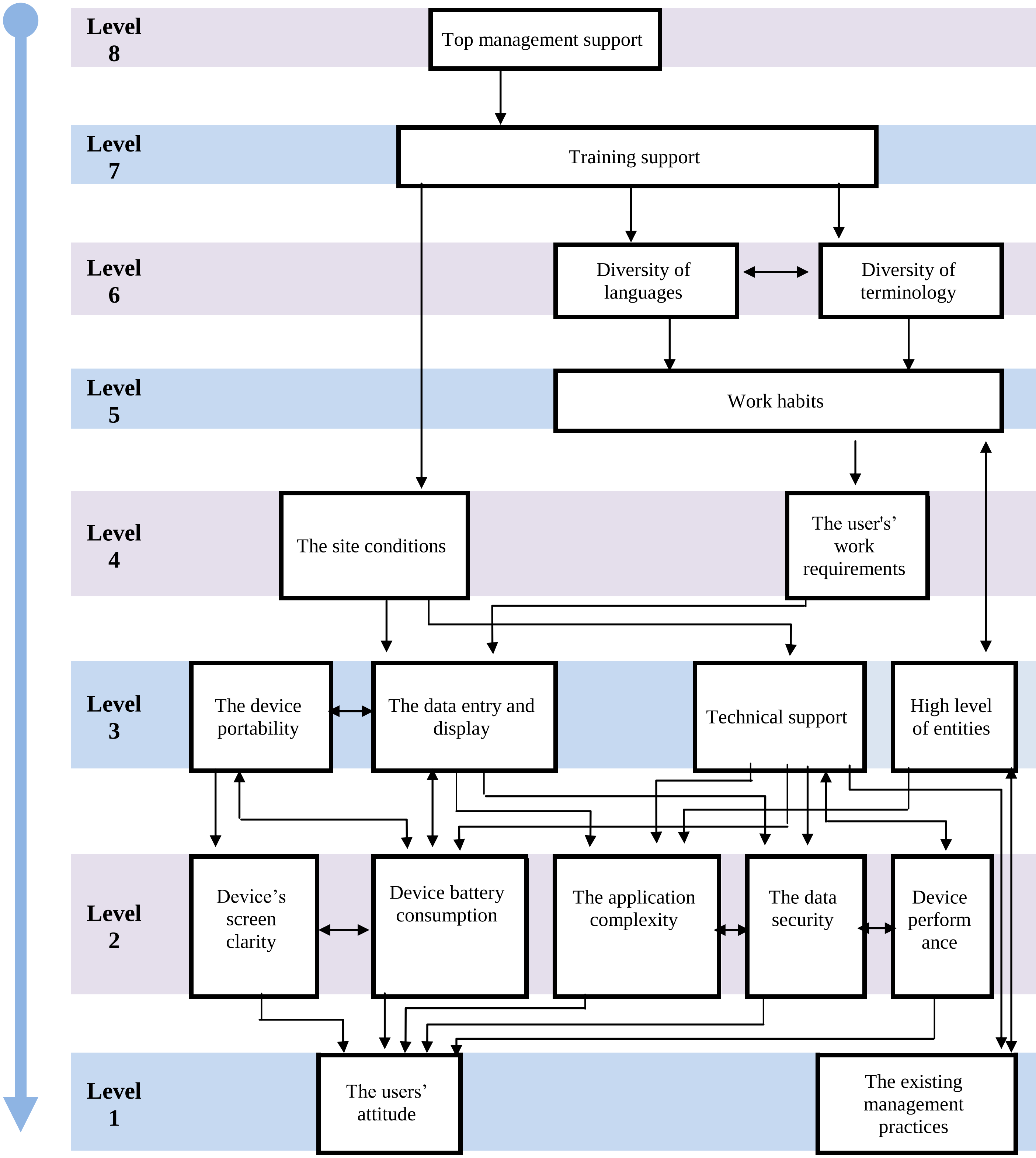


Figure 8-1: Final diagram of the relationships among the challanges

From the final reachability matrix, the structural model is produced. If a relationship exists between the items j and i, an arrow pointing from i to j shows this. The diagram below (8-1) represents 8 levels that are considered important for the successful implementation of mobile computing in Saudi Arabia. The ISM displayed that the key aspect that is considered to be of the extreme importance, at level 8, is “top management support”. This element presented that it has significant effect on “the availability of training support”. The top managers have to realise the potentials of mobile computing and its abilities in order to implementing it. The next step is to provide the required training for their staff. The training have to overcome the diversity of terminologies by standardising it and support different languages. Also, the training have to consider site conditions and provide precaution guide for the staff in order to maximise the use of mobile device on-site.

Further importance would be given to “work habits” as it correlates with “high level of entities” and effect “the work requirements”. The work habits of the project managers of assign the roles and responsibilities for their staff and managing the different groups as well as managing the required information have to be identified and structured. The lines of management have to be drawn. At level 4, ‘site conditions’ and ‘information requirements’ effect ‘the data entry and display’ in the device. In level 5, the technical support’ get effected by ‘the site conditions’ as the mobile devices have to be supported in case of damage happens to it.

‘The data entry and display’ has significant association with ‘the device portability’. As entering or presenting the information on a large screen such as the tablet which provide clear view effect the portability of the device when the staff performing on site. On the other hand, the smartphone provide greater portability than the tablet but less ability for entering or presenting the information. The staff have to decide which device they prefer to use according to its portability and data entry and display. The next level (2), ‘the device battery consumption’ has a significant association with the ‘screen clarity’ as high definition screen consume the battery. Also, the device battery consumption have a significant association with both the device portability and the data entry and display. The 'application complexity' get effected by the 'data entry and display' in which the data is presented and the interface organised.

Also, the availability of the technical support help to maintain the application complexity. The 'data security' have significant association with 'application complexity' as well as 'device performance'. The maximum security of the data increases the complexity of the application, and requires extensive processing demand high computational capacities. However, all items in level 2, effect the users' attitude toward the acceptance of mobile computing. 'The existing management practices' has significant association with 'high level of entities' that means they effect on each other as teams are temporary, onsite relationships are constantly changing. The ''technical support' has an effect on 'the existing management practices' as it needed to maintain the system for the management practices. Generally, the strategy of successful mobile computing implementation will come from concentrating on the important items and working through to the least important ones. Improvement through all the levels is required to ensure a successful strategy for effective mobile computing implementation in Saudi Arabia.

8.3.5. MICMAC Analysis – Classification of Implementation Items

MICMAC (impact matrix cross-reference multiplication applied to a classification) analysis. All the implementation variables have been classified into four groups, based on their driving power and dependence (Table 8-5). The four categories are (Attri et al, 2013, p.7):

I. Autonomous factors: These factors have weak drive power and weak dependence power. They are relatively disconnected from the system, with which they have few links, which may be very strong. The items that fall under the autonomous category:

Table 8-8: Autonomous Factors

1	**The users' work requirements**	**12**	**The site conditions**
4	**The existing management practices**	**13**	**The device portability**
6	**Device's screen clarity**	**15**	**Diversity of languages**
7	**The data security**	**16**	**Diversity of terminology**
8	**IT infrastructure**	**17**	**Work habits**
9	**Technical support**	**18**	**High level entities**
10	**Device battery consumption**		

II. Dependent factors: These factors have weak drive power but strong dependence power. This measure includes users' attitude (5), the technological complexity (11), and the data entry and display (14).

III. Linkage factors: These factors have strong drive power as well as strong dependence power. These factors are unstable in the fact that any action on these factors will have an effect on others and also a feedback effect on themselves. In the current research there are no linkage factors.

IV. Independent factors: These factors have strong drive power but weak dependence power. A factor with a very strong drive power, called the 'key factor' falls into the category of independent or linkage factors. The training support (2) and the top management support (3) fall under this category.

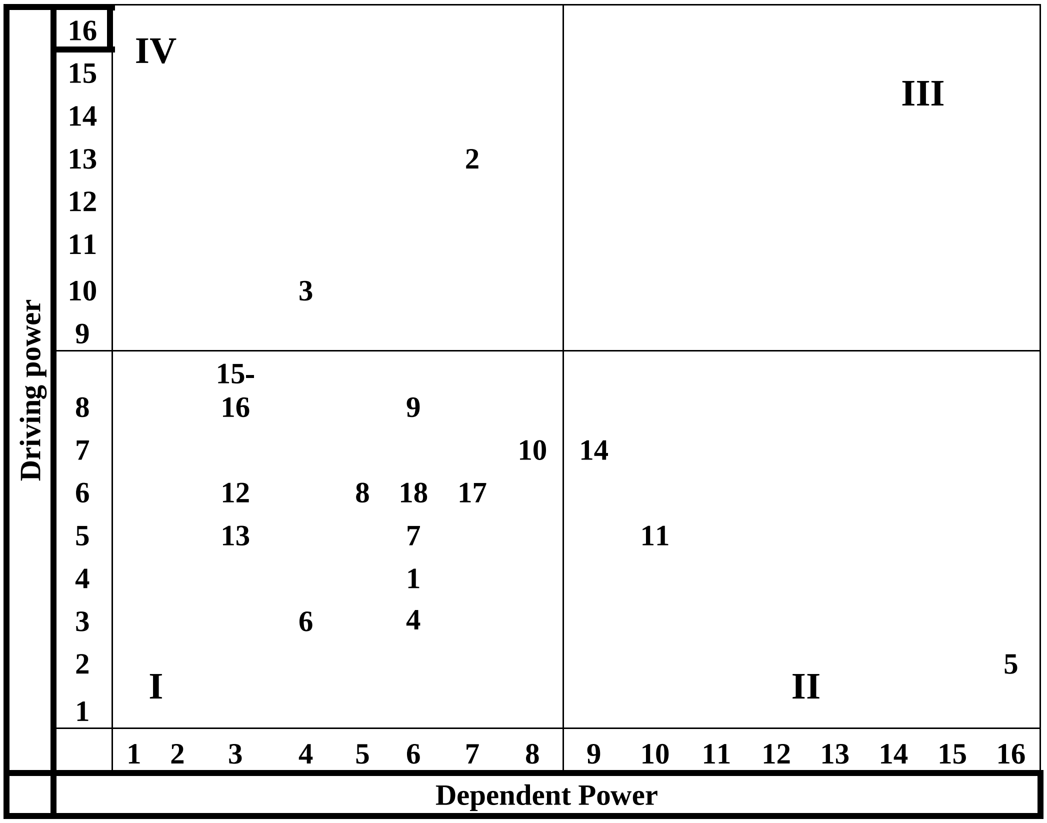


Figure 8-2: Driving power and dependence diagram

8.4. Summary

This chapter presents the framework development in Section 8.3.1, which develops a Structural Self-Interaction Matrix in coordination with experts to classify the relationship between two challenges items through the use of the symbols V, A, X and O. This requires the experts to discuss the items to determine the relationships among them. After creating Table 8-2, the ISM systematic processes were followed to come up with the framework (Figure 8-1) in Section 8.3.4, and explain the rationale underlying it. Then, another focus group was held to evaluate the result. The evaluation discusses and confirms the framework, as it reflected the experts' classification of the relationships between the items at the first meeting. This meeting strengthened the credibility of the framework and the rationale underlying it.

Chapter 9: Conclusions and Recommendations

9.1. Introduction

Mobile computing is a new phenomenon in Saudi Arabia; one that is yet to be fully utilised, as it continues to face multiple challenges. The main aim of this research was to study how mobile computing is implemented and how it can be exploited to enhance information provisioning support for contractors' personnel working on construction-sites in Saudi Arabia. This study had six objectives, which are listed below alongside the main findings that relate to them.

9.2. Key Research Findings Related to Objective 1

To develop an understanding of the literature in the area of mobile computing applications for site-based construction workers

The literature review (Chapter 3) charts the increased acceptance of the mobile phone as a ubiquitous tool in the home and workplace. Attitudinal changes and developments in the technology lend weight to Kim et al.'s (2013) confidence that the potential of smartphone technology would lead to a "paradigm shift of conventional construction management practices" (Kim et al., 2013, p.422). The outcome from this objective, in over the course of a ten-year period, the tone in the literature (Chapter 3) changed from one of scepticism to a growing confidence, that with management support, mobile computing could make a notable contribution to speeding up and streamlining work processes. The increasingly distributed nature of construction project teams, continuing technological development, the variety of disciplines involved, and the growing need for real time information and service delivery are all factors indicating a genuine need exists, which could be satisfied by some combination of mobile computing technologies. However, as Davies and Harty (2013, p.22) explained, "successful implementation of new and innovative Information Technology in construction requires the development of strategic implementation plans prior to IT project commencement".

9.3. Key Research Findings Related to Objective 2

To identify the benefits and challenges in providing timely and relevant information to site-based construction workers engaged in public sector construction projects within Saudi Arabia.

The literature (Chapter 3, Section 3.5.3) is clear about the benefits typically associated with mobile computing. These include a reduction in paperwork, sharing up to the minute data to provide accurate real-time information and fast decision making, and generally improved on-site communication with the project team. These are generally universal benefits, which apply regardless of size or location of a company. However, the challenges of implementing and using on-site mobile computing (Chapter 3, Section 3.5.4) are subject to context. Sharing a mobile information system would deliver the following improvements; introduce a structured and standard process to help prevent human error, reduce the risk of items of work being forgotten, improve clash detection and draw clear lines of accountability, reinforced by a trackable work record, and shared access to relevant project information, helping put structure around issues associated with quality control and tracking repairs.

The introduction of a standard documentation process, would improve workflow by recording and sharing data and using checklists to control the completion of tasks, aside from the benefits already listed. The current practice of using mobile phones for voice calls only, disregards their potential for data storage and the sharing of up to date information. Personnel in Case A (Chapter 6, Section 6.4.1.2) have shared and exchanged pictures via WhatsApp, but have not saved written information and data. Both the construction personnel interviewed for this research (Chapter 6), and the literature (Chapter 3), agree that mobile computing would enhance on-site communication and collaboration. Informed decision making based on up to the minute information would increase efficiency and help reduce the risk of costly repair work. Documenting, registering and mapping quality deficiencies would help build a culture of excellence. By ensuring mistakes are mapped and therefore easily located, problems would be anticipated, or at least dealt with, before the continuation of construction makes errors more costly to repair.

The benefits commonly linked to mobile computing include issues such as cost savings and increased efficiency. However, a less easily measured, but arguably more valuable intangible benefit, is linked to the change in work culture and values. Greater collaboration would give workers an increased sense of ownership and clarify chains of responsibility. Tracking job completion would link work-progress to the individuals or group responsible, thereby making them accountable and answerable for their skills and performance. The entire work process would then be transparent to management and the workforce, making it difficult for the slipshod and lazy to escape their responsibilities. The practice of making last minute modifications to building and design plans cannot be eliminated by technology. However, the rewriting and consequent need to retype, photocopy and manually distribute the revised documents can be minimised. As important as the time savings involved is the opportunity to offer assurance to on-site engineers that they are working to accurate and up to date plans.

9.4. Key Research Findings Related to Objective 3

To determine key information requirements for mobile construction workers in Saudi Arabia

The main purpose of using mobile computing is to serve and enhance the information flow. The literature (Chapter 3, Section 3.4.3) and the findings of Chapter 6 describe the execution of plans, issuance of orders and making of requests currently relies on word of mouth exchanges, and printed records have played a secondary and ‘routine’ role. Therefore, repositories of construction expertise with the know-how to complete an array of work tasks, from checking and measuring progress, to dealing with the unexpected, lies in the knowledge, experience and skills of the site staff themselves. This objective is expressed in the main research problem, which is that using traditional methods not only fails to share and make data recording work in progress accessible, it also fails to share take advantage of the potential pool of expertise for on-site problem solving. In contrast to speedy and simple patterns of communication, methods associated with sharing and recording information are protracted and inflexible, and make no provision for immediate responses.

Mobile devices (Chapter 3) enable data to be updated from the point of activity, overtaking outdated data entry by office based staff. Since the team of engineers using the mobiles can all access the same files in real-time, errors to do with timing and misunderstanding are less likely. Informed decisions can be made with greater certainty that all concerned are 'on the same page'. Under present conditions, from the findings of Chapter 6 that decisions are informed by out of date information based on "weekly or monthly reports", which are themselves out of date. The Site Manager (B2) described the lengthy processes involved in the preparation of weekly reports. He receives daily reports from other site engineers via email. His responsibility is to analyse and organise information and "to put it in the weekly reports". He then sends it to the Construction manager (B1) who checks it before sending it to upper management.

Such reports become "lag indicators", or repositories of outdated information. Thus, because they are out of date, they indicate recent, not present trends. As a consequence, the reporting of on-site issues is "often delayed" (Ennova, 2011, p.2). A file sharing system would, at project completion, produce an "accurate timeline record of exactly what happened during project execution", allowing supervisors to spend more time in the field, enabling them to base decisions on up to the minute data (Ennova, 2011, p.4). Having a repository of information, to track the field work from start to completion, would benefit forthcoming projects by forming the basis of a future plan of action, and reduce reliance on the "memory and experience" of project managers. The reality is that, because of the time taken for preparation and distribution, the paper reports produced by project managers are commonly based on two or three week-old information from the field.

A file sharing system such as the cloud would ensure up to date reports were available whenever they are needed. Overall, the system in use is reactive rather than proactive. In another industry, Banking or Insurance for example, basing management reports on out of date information would be commercially damaging. The time may come when construction can no longer rely on outdated information. Providing managers with accurate and timely information about companies is key to the ability to make informed decisions (Dima, 2009, p.1), “accurate and timely” means collecting data via digital or electronic means at construction-sites during the completion of jobs.

9.5. Key Research Findings Related to Objective 4

To explore the existing technology usage in Saudi Arabia site-based construction workforce

The findings of Chapters 5 and 6 confirmed that the existing communications in Saudi Arabia are mainly conducted through voice-calls, or paper based documents and emails. This is in line with the literature (Chapters 2 and 3). These methods are traditional communication methods, which rely on centralised information, making the project manager responsible for communications between the construction team and top management. The manager’s considerable power is exercised in the process of assigning work (some roles are easier and more desirable than others) and assessing completed tasks. The internal competition this generates reinforces loyalty and allegiance to the site superior.

The project manager defines the task execution values, and then, workers follow his orders and conform to his expectations when completing tasks. The manager retains decision-making authority and is often “the ‘correcting’ manager as well as the only judge of performance quality” (Hooijberg & Broeckx in Hooijberg & Hunt (eds), 2007, p.56). The project manager’s unwillingness to delegate tasks was a feature referred to often in interviews (Chapter 6). The outcome of the project manager’s determination to maintain his position of superiority is to suppress the self-confidence of subordinate managers, thereby reducing their morale and efficiency. In conclusion, a mobile IT system would make empower subordinate managers, through affording them access to updated photos and written comments, to data on the quality of ongoing tasks, and the time taken to complete them. Removing the project manager's role as the only judge of performance quality would dilute his power.

We have seen that large Saudi construction firms are mainly family owned, and that their management style is also instructional and hierarchical. We have also seen how it can be difficult for workers in subordinate management positions to gain access to information concerning changes and developments in projects. The Interviewees (Chapter 6) commented on the stress of the work and stated that they favour speedy communication methods, which can relieve time pressures. They have also referred to competition between factions based on groups or individuals taking credit or blame for completed work.

Moreover, users will be able to record comments and read comments left by other users. In the context of working on-site, this is a recording and information storage tool. However, this research has argued that, gradually, over a period of time, planning procedures digitally, and mapping tasks on a computer would have the effect of modifying work practices because people will see and comment on process improvement. No IT system can prevent conflict and collision between people and activities, but the independent planning of each specialist group's work, and the transparent record that links working teams and distinguishes between them, will assist site managers to "organise the site work".

9.6. Key Research Findings Related to Objective 5

To develop a strategy for the successful implementation of the provision of pervasive mobile digital technology to support the information needs of site-based construction workers

This goal has been accomplished by selecting a number of factors that challenge mobile computing in Saudi Arabia. 23 challenges were investigated (Chapter 3, Section 3.5.4), but only those variables that resulted in greater agreement were identified as the most important (18 items) (Chapter 7, Section 7.5). Chapter 8 uses the results of the discussion in Chapter 7 to develop the framework and validate it using Interpretive Structural Modelling (ISM), generated through a focus group. Interpretive Structural Modelling is generally deployed to reveal “shared mental models” (Warfield, 1974). These shared mental models are then used to compose a tentative theoretical framework, as they encapsulate how individuals understand and explain the particular phenomenon being studied (Warfield, 1974).

Looking at challenge factors that affect the implementation of mobile computing for managing and controlling construction sites within the Saudi construction industry, and their level of importance in assessing the relationship between factors to come up with the framework (Chapter 8, Section 8.3.4), and categorise the factors according to their driving and dependent powers (Chapter 8, Section 8.3.5) into Autonomous, Dependent, Linkage and Independent factors. The outcome of the ISM can be used for forthcoming studies about how to successfully implement mobile computing in Saudi Arabia.

9.7. Key Research Findings Related to Objective 6

To validate the implementation strategy

To meet this goal the researcher designed a model using Interpretive Structural Modelling (ISM) to summarise the challenges affecting mobile computing in Saudi Arabia. The framework development in Section 8.3.1 carried out by experts to classify the relationships between challenges using the symbols V, A, X and O required the experts to discuss the items to determine the relationships between them. After completing the ISM processes, the focus group met again to validate the results, which were, according to order of importance: top management support for mobile computing; the availability of training support; diversity of languages; diversity of terminology; work habits; users' work requirement; site conditions; device portability; data entry and display; technical support; high level of entities; device's screen clarity; device battery consumption; technological complexity; data security; IT infrastructure; users' attitudes; existing management practices. The validation discusses and confirms the framework, as it reflects the experts' classification of the relationships between the items at the first meeting. This meeting strengthens the validity of the framework and the rationale underlying it.

9.8. Contribution of this Study to Practice and Knowledge

The construction industry in Saudi Arabia is developing and still under investigation by researchers. The contribution of the study is significant, as it is considered the first of its kind to be conducted in Saudi Arabia. It has evaluated the affordances of mobile computing, examining its benefits and challenges, priorities, site based worker's needs, and identification of key information. Using questionnaires and interviews and a focus group review, this study has presented conclusions about the main factors associated with the implementation of mobile computing. The research has led to a better understanding of mobile computing, and simplified the principal factors that contractor companies should attend to in order to implement mobile computing in Saudi Arabia. Davies and Harty stress that "successful implementation of new and innovative Information Technology in construction requires the development of strategic implementation plans prior to IT project commencement" (2013: 22). The strategic framework targets the contractor companies, which provides a road map for mobile computing to be successfully implemented. Similarly, this study has delivered a solid platform for upcoming studies, which aims to expand knowledge in this field. The current results will be published to maximise the value of the research. It is also intended that it will be translated into Arabic to make it more accessible to stakeholders.

9.9. Research Limitations

The conclusions drawn within this thesis must take into account limitations in data collection and the available literature and focus, especially when extrapolating conclusions reached in the construction industry of a single country to that of another:

- The Saudi construction literature concentrates on project delays, and identifying the problems causing delays, at the expense of finding solutions to overcome them.
- There are some gaps in the available KSA literature regarding the communication tools that are utilised, which are associated with company size, and the skills of the personnel. The available literature concentrates on a specific sort of project, those built in remote areas of Saudi Arabia.
- In global research, many researchers have discussed the potential for using mobile technology in construction projects, but few have developed prototypes.
- Much of the data collected by previous researchers regarding mobile technology has swiftly been superseded by technological developments, making it out of date.
- There is very limited literature that focuses on the actual implementation of mobile technology at construction sites.
- This research focuses on large and complex public projects constructed by top ranked contractors in the "Building" category, according to the Saudi Agency of Contractors Classification at the Ministry of Municipal and Rural Affairs (MACC, 2013). There were some ongoing projects, but the contractors declined to participate in this research; thus, the researcher conducted the third case study in the "Road" category, which is still a large one.

9.10. Conclusion

This research aims to develop a strategy for the successful implementation of mobile computing. Identifying a particular, general plan that would enable any construction company in KSA to implement mobile computing was challenging. This could not happened without meeting the objectives of this research. The objectives of this research were the steps taken in order to meet the overall research aim. The first objective was to review up-to-date literature in the area of mobile computing applications for site-based construction workers. The literature published prior to 2010 was particularly vulnerable to technological advances and therefore redundant, as new devices and platforms have since emerged. The literature published in the last five years has been more confident in its assessment of the feasibility of onsite mobile computing, due to the now almost universal ownership of smartphones. This familiarity with constantly improving and increasingly user-friendly software has shifted the discussion from consideration of the potential for improving onsite communication, toward how this can be achieved in practice. This is where the second objective arises, which was to identify the benefits and challenges of utilising mobile computing to provide a better understanding of the feasibility of its implementation.

The third and fourth objectives aimed to understand the current practice, in particular to determine and explore the key information requirements for mobile construction workers and the existing technology usage amongst the Saudi Arabian site-based construction workforce. The site-based construction workforce currently relies on traditional communication methods supplemented by paper-based documents and voice calls, which means information is centralised and overseen by the project manager, who is responsible for communication between the construction team and top management. The internal competition this generates reinforces loyalty and allegiance to the superior site officer. In other words, the current practice with regard to use of mobile phones is for voice calls only, disregarding their potential for data storage and the sharing of up to date information.

All of the above objectives contribute to meeting the research aim by helping to develop a framework for implementing mobile computing using Interpretive Structural Modelling

(ISM), generated through use of a focus group. ISM is a tool for developing and validating a framework. The focus group met again to discuss and validate the framework, which reflected their initial classification of the relationships between the items identified in the first meeting. The on-site use of mobile computing in a Saudi context can be easily implemented if contractor companies follow the framework steps. However, the results of this research can also be applied in other countries with similar characteristics to the KSA, by modifying the provided framework strategy.

9.11. Recommendations for Practice

Synchronous communication should be established to relax the hierarchical lines of management communication, to open up pathways allowing middle management to show more initiative. However, it is anticipated that management will only be willing to adopt a more open and collaborative set of values if mobile computing is perceived as successful, and mobile computing depends upon top management support and goodwill for its success. Mobile computing would make it possible to formally document a system of roles and processes for individuals and teams to complete, leading to process integration and knowledge integration. The work process could then be tracked, measured and knowledge shared.

Multiple points need to be considered regarding mobile technology, management of project information, processes, and user requirements. In terms of technology, a unified approach will require satisfaction of a set of circumstances, such as the standardisation of mobile communications protocols and data formats, exchanged between different sectors. A process-oriented approach, that develops standard operating procedures to achieve consistency, is pivotal to the success of any business (Perumal & Abu Bakar, 2011). Dainty at el, (2006) and Davies (2008) refer to two distinct approaches; either to use the accustomed managerial and communication processes as the model for a new IT framework, or to change existing processes so that IT determines the practice. This research recommends the striking of a balance between these two distinct, but not mutually exclusive approaches.

A unified approach to project management (traditional work practices arrive at a ‘best-practice’ equilibrium) involves finding agreement on different views concerning the project information, defining the interrelationships between the information expressed by these different views, and modifying project management tools and procedures to work with integrated views (Froese 2010). A digital system of recording work progress, and sharing the information recorded, would build structure, accountability, a track-able audit trail and transparency into work processes. It would also increase quality (using check-lists to rule out omissions), speed (by mapping and sharing site locations), collaboration and transparency (managers can see updated reports of who did what, where and when). For a digital system to be a productive tool, the managers using it would have to show initiative, be procedural and also attentive to detail.

Decision making in the field of construction requires the processing of large amounts of information, and the managing of processes and procedures that integrate a great variety of factors (Jato-Espino et al., 2014). Making decisions in information-rich environments can be facilitated by using IT to filter available data. However, project managers, who have the power to change on-site relationships and processes, must be encouraged to focus on more than hardware systems. They must centre their attention on the development of managers’ capabilities, to allow them to re-order work from a system that relies on the word of mouth and face-to-face instructions given by a few, towards a more structured and accountable system based on shared responsibility. This approach would encourage collaboration and also, eventually, create value based not only on cost savings, but also on improvements in the quality of work. The interviews tell us that site engineers have the capability to operate mobile, as they are already familiar with the operations smartphones and tablets can perform. In addition, we acknowledge many decisions regarding design need to be made on the basis of user–computer interactions. Identifying these factors will help to fulfil the maximum potential of mobile computing within construction use.

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The Appendices

Appendix A: Ethical Approval

Academic Audit and Governance Committee

College of Science and Technology Research Ethics Panel (CST)

To **Naif Alaboud (and Dr Zeeshan Aziz)**

cc: **Prof Charles Egbu, Acting Head of School of SOBE**

MEMORANDUM

From **Nathalie Audren Howarth**, **College Research Support Officer**

Date **20th November 2013**

Subject: **Approval of your Project by CST**

Project Title: **Development of a Framework to Enhance Information Provisioning Support for Mobile Construction Workers in Saudi Arabia**

REP Reference: **CST 13/109**

Following your responses to the Panel's queries, based on the information you provided, I can confirm that they have no objections on ethical grounds to your project.

If there are any changes to the project and/or its methodology, please inform the Panel as soon as possible.

Regards,

Nathalie Audren Howarth
College Research Support Officer

Appendix B: Root Cause Analysis of Key Factors Causing Project Delays in Saudi Arabia

People Related Factors Causing Project Delays

Factor	Description	Comments
Shortage of labourers	Lack of workers number which reflected in late work completion	Assaf and Al-Hejji, 2006
Unqualified work-force	Low skilled or semi-skilled labourers	Assaf and Al-Hejji, 2006; Albogamy et al. 2012
Low productivity level of labourers	Slow at producing work	Assaf and Al-Hejji, 2006
Poor qualification of the Contractor's technical staff	low educated or experienced personnel	Assaf and Al-Hejji, 2006; Albogamy et al. 2012
Inflexibility (rigidity) of consultant	Strict behavioural attitude by the consultant	Assaf and Al-Hejji, 2006; Alkharashi el at 2009
Inadequate experience by contractor and consultant	Inappropriate or unqualified experience regarding the work scope	Assaf and Al-Hejji, 2006; Alkharashi el at 2009

Management Behaviour Related Factors Causing Project Delays

Factor	Description	References
Owners' poor communication with the construction parties	Inadequate linkage between parties	Alkharashi el at 2009
Delay in progress payments by owner	Lengthy managerial process by the owner	Assaf and Al-Hejji, 2006; Alkharashi el at 2009;

		Alsuliman et al. 2012
Ineffective planning and scheduling of project by contractor	Poor planning and preparation of the work by the contractor	Assaf and Al-Hejji, 2006; Albogamy et al. 2012; Alkharashi el at 2009
Slowness in decision making process by owner	Inexperienced or poor behaviour from personnel	Assaf and Al-Hejji, 2006; Alkharashi el at 2009
Change orders by owner during construction	Insufficient project information	Assaf and Al-Hejji, 2006
Late procurement of materials	Poor management or preparation of the work	Assaf and Al-Hejji, 2006
Poor site management and supervision by contractor	inexperienced or autocratic management behaviour	Assaf and Al-Hejji, 2006; Alkharashi el at 2009

Environment Related Factors Causing Project Delays

Factor	**Description**	**References**
Hot weather's effect on construction activities	The harsh climate conditions	Assaf and Al-Hejji, 2006
Effects of subsurface conditions (soil, existing of utilities, high water table, etc.)	The poor project information or certainty of the site conditions	Assaf and Al-Hejji, 2006

Work Conditions Related Factors Causing Project Delays

Factor	**Description**	**References**
Type of project bidding and award	The not united bidding and award among all public projects	Assaf and Al-Hejji, 2006
Difficulties in financing project by contractor	Logistic financial liquidity obstacles	Assaf and Al-Hejji, 2006; Albogamy et al. 2012

Conflicts encountered with subcontractors' schedule in project execution	Poor preparation of the work or autocratic management behaviour	Assaf and Al-Hejji, 2006

Design Related Factors Causing Project Delays

Factor	**Description**	**References**
Late in reviewing and approving design documents by consultant and owner	Lengthy or antique managerial process	Assaf and Al-Hejji, 2006; Alkharashi el at 2009
Delays in producing design documents	Lengthy or antique managerial process or autocratic management style	Assaf and Al-Hejji, 2006; Albogamy et al. 2012
Mistakes and discrepancies in design documents	Inexperienced or unqualified personnel	Assaf and Al-Hejji, 2006

Appendix C: Semi-structured Interview

Section 1. The construction communication

1. Which sort of communication tools are being used? And give more than three reasons for utilizing it?
2. What is the existing mechanism of information retrieval and transfer on construction sites?
3. In your experience, which tools are used and how often (e-mail, walkie-talkies, tablet computers, Videos, Photos, Text messages, Paper-based, laptops, Voice-phone call, etc)?
4. Have you had noticed any problems with the communication technology e.g. phone network or internet signal? If there was problem with the communication signal, what are the processes to follow?

Section 2. The key information requirements and the communication processes

1. What is the Organisational Breakdown Structure?
2. Which personnel do you communicate with him frequently? And about what?
3. How often do you visit the site?
4. Who is the decision maker?
5. How do you know, that you have the newest information, when you are performing your task?
6. What are the most important activities?
7. What is your role?
8. What is your responsibilities?
9. Which sort of information do you produce, receive and with which tools?
10. What are the tasks that use paper based documents' with it especially on-site?
11. Do you use internet for information exchange? Which tasks you are using it with?
12. How do construction personnel manage information on construction sites?
13. What are the information which on-site staff would like to have access to whilst they on-site?
14. What is the process of requesting materials?
15. What is the process of requesting information?

Section 3. Mobile computing technology

1. If an IT-system was accessible on the construction site, would you use it?
2. Do you have access to digital project material on the construction site?
3. Have you used mobile applications on the construction site?
4. Do you think that IT could be used to increase the productivity on the construction site?
5. What sort of problems that mobile computing can solve?
6. In your opinion, What are benefits from implementing and utilizing this technology?
7. In your opinion, What are barriers that effect the implementation and utilization this technology?
8. What are the requirements of the user?
9. Is the site engineers capable of utilizing this technology?
10. Which device is more suitable (tablets, mini tablet, smartphones)?

Section 4. The key challenges that effect the implementation of mobile computing

1. Rank the following characteristics on their relative importance of effect on the adoption mobile computing technology on site.

- **Management challenges**

Item	Rank
U. The effect of top management support on the uptake of mobile computing	
R. The effect of existing management practices that reluctant to change when implementing mobile	
T. The effect of users' attitude on the acceptance of mobile computing	
V. The users' work requirements affect the adoption of mobile computing	
S. The availability of training support on the uptake of mobile computing	
W. The effect of staff proficiency in IT skills on mobile computing	

- **Technology challenges**

Item	Rank
A. The data security issue effect utilising mobile computing	
D. The availability of technical support on the uptake of mobile computing	
C. The Device performance that affect mobile adoption	

B. The effect of battery consumption on utilising of mobile device	
E. The effect of the device’s screen clarity on presenting the project information	
H. The device capabilities that impact on the mobiles’ utilisation	

- **Usability challenges**

Item	Rank
I. The effect of the complexity of mobile application on adopting mobile computing	
F. The data entry and display approaches effect adopting mobile computing	
L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device	
K. The portability (size and weight) of the device effect adopting mobile device	
J. The diversity of terminology and semantics among project members’ effects the mobile adoption	
Q. The diversity of project members’ languages effects the mobile adoption	
G. The effect of the device’s screen size on which data are displayed	

- **Cultural challenges**

Item	Rank
M. The effect of high level entities in the project on the adoption of mobile computing	
N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.	
P. The effect of social influence on the user's adoption of mobile computing	
O. The level of education on the diversity of nationals (multicultural) effects mobile Implementation	

2. The discussion about each factor
    - The most important
    - The least important
    - The important factor over four
    - Why do you agree with factors
    - How satisfied are you with this categorisation

Appendix D: The Survey Questionnaire

1. Your area of work:
    1. [ ] Public sector
    2. [ ] contractor companies
    3. [ ] consultancy
2. Your area of specialisation:
    1. [ ] Engineering
    2. [ ] architecture
    3. [ ] management
3. Your highest educational level:
    1. [ ] Below Bachelor
    2. [ ] Bachelor
    3. [ ] Higher Diploma
    4. [ ] Master
    5. [ ] PhD
4. How much inter-collaboration exists in your construction projects
    5. [ ] Extremely good
    4. [ ] Very good
    3. [ ] Neither
    2. [ ] Not good
    1. [ ] Not good at all
5. What is your level of satisfaction with existing communication systems prevalent in the construction projects?
    5. [ ] Extremely good
    4. [ ] Very good
    3. [ ] Neither
    2. [ ] Not very good
    1. [ ] Not good at all

6. Rank the following requirements on their relative importance on-site (at the point of work) according to the scale. Scale each one 1 to 5. 1 Not required at all, 5 Absolutely Required.

Demands	Rank	Demands	Rank
a. Requests for information	1 2 3 4 5	b. Subcontractor information	1 2 3 4 5
c. Task allocation	1 2 3 4 5	d. Quality assurance	1 2 3 4 5
e. work directory	1 2 3 4 5	f. Field observations	1 2 3 4 5
g. Monitoring progress	1 2 3 4 5	h. Work package information	1 2 3 4 5
i. Monitoring health and safety on site	1 2 3 4 5	j. Daily report	1 2 3 4 5
k. changing orders	1 2 3 4 5	l. Delay recording	1 2 3 4 5
m. Quality inspections	1 2 3 4 5	n. Reporting violations	1 2 3 4 5
o. schedule updates	1 2 3 4 5	p. accident reporting	1 2 3 4 5
q. Site investigation	1 2 3 4 5	r. Exception reporting	1 2 3 4 5
s. equipment management	1 2 3 4 5	t. Site diaries	1 2 3 4 5
u. Material Management	1 2 3 4 5	v. On-site accounting of operatives/visitors	1 2 3 4 5
w. Activity Duration	1 2 3 4 5	x. Defect management	1 2 3 4 5
y. View a drawing	1 2 3 4 5	z. Weekly report	1 2 3 4 5
aa. Annotate a drawing	1 2 3 4 5	bb. Monthly report	1 2 3 4 5
cc. Read methods statement	1 2 3 4 5		

Others, specify: ....

7. Please rate which communication tool is used mostly in construction site currently? Scale each one 1 to 5. 1 Not used at all, 5 most used.

a) phone calls 1 2 3 4 5
b) Paper-based 1 2 3 4 5
c) Text messages 1 2 3 4 5
d) Computes 1 2 3 4 5
e) Cameras 1 2 3 4 5
f) Fax 1 2 3 4 5

g) RIDO 1 2 3 4 5
h) Others, specify: ....

8. Rank the following characteristics on their relative importance to the project team members according to the scale. Scale each one from 1 to 5. 1 not important at all, 5 very important.

Item	Rate				
	1	2	3	4	5
A. The data security issue effect utilising mobile computing					
B. The effect of battery consumption on utilising of mobile device					
C. The device performance that affect mobile adoption					
D. The availability of technical support on the uptake of mobile computing					
E. The effect of the device's screen clarity on presenting the project information					
F. The data entry and display approaches effect adopting mobile computing					
G. The effect of the device's screen size on which data are displayed					
H. The device capabilities that impact on the mobiles' utilisation					
I. The effect of the application complexity on adopting mobile computing					
J. The diversity of terminology and semantics among project members' effects the mobile adoption					
K. The portability (size and weight) of the device effect adopting mobile device					
L. The effect of the site conditions (e.g. temperature, humidity, dust) on utilising mobile device					
M. The effect of high level of entities in the project on the adoption of mobile computing					
N. The effect of people's resistance to change due to engrained work habits on the utilisation of mobile computing.					
O. The level of education of the diversity of nationals (Multicultural) effect the mobile Implementation					
P. The effect of social influence on the user's adoption of mobile computing					
Q. The diversity of project members' languages effects the mobile adoption					

R. The effect of existing management practices that reluctant to change when implementing mobile					
S. The availability of training support on the uptake of mobile computing					
T. The effect of users' attitude on the acceptance of mobile computing					
V. The user's' work requirements affect the adoption of mobile computing					
U. The effect of top management support on the uptake of mobile computing					
W. The effect of staff proficiency in IT skills on mobile computing					

9. In your opinion, which sort of technology is the most appropriate to be used by the mobile construction personnel's for information exchange.

    1. Smartphones
    2. Tablets
    3. Laptop

Appendix E: Descriptive Statistics

Section 1: The respondent background

Table 1.1: The area of work

Type of organization	Number	Percentage
Public sectors	37	18.0%
Contractors	141	68.8%
Consultants	27	13.2%
Total	205	100%

Table 1.2: The field of study

Study	Number	Percentage
Engineering	106	75.2%
Architecture	20	14.2%
Management	15	10.6%
Total	141	100%

Table 1.3: The highest educational level

level of educational	Number	Percentage
Below bachelor	18	12.8%
Bachelor	95	67.4%
High diploma	9	6.4%
Master	8	5.7%
PhD	11	7.8%
Total	141	100%

Section 2: Factors related to construction projects

Table 2.1: The inter-collaboration exists in the construction projects

The collaboration	Number	Percentage
Not good at all	2	1.4%
Not good	11	7.8%
Neither	53	37.6%
Good	60	42.6%
Extremely good	15	10.6%
Total	141	100%

Table 2.2: The level of satisfaction with existing communication systems prevalent in the construction sites

The satisfaction level of communication	Number	Percentage
Not good at all	6	4.3%
Not good	15	10.6%
Neither	56	39.7%
Good	54	38.3%
Extremely good	10	7.1%
Total	141	100%

Table 2.3: The utilisation of the communication tools in construction site

Types of communication tools	Not important at all	Not important	Neither	Important	Very important
A. Phone Calls	6.4%	2.1%	9.9%	18.4%	63.1%
	9	3	14	26	89
B. Paper-Based	7.8%	5.0%	17.7%	39.7%	29.8%
	11	7	25	56	42
C. Text messages	22.0%	22.7%	33.3%	12.8%	9.2%
	31	32	47	18	13
D. Computes	6.4%	4.3%	30.5%	22.7%	36.2%
	9	6	43	32	51
E. Cameras	5.0%	7.1%	19.9%	33.3%	34.8%
	7	10	28	47	49
F. Fax	12.1%	17.7%	37.6%	18.4%	14.2%
	17	25	53	26	20
G. RIDO	31.9%	9.9%	19.1%	23.4%	15.6%
	45	14	27	33	22

Table 2.4: The weight of the communication tools in construction site

Types of communication tools	Not important at all	Not important	Neither	Important	Very important				SI
	0.2	0.4	0.6	0.8	1	WI	FI	TR	
Phone Calls	9	3	14	26	89	121.2	1	141	85.96
Cameras	7	10	28	47	49	108.8	1	141	77.16
Paper-Based	11	7	25	56	42	106.8	1	141	75.74

Computes	9	6	43	32	51	106.6	1	141	75.60
Fax	17	25	53	26	20	86	1	141	60.99
RIDO	45	14	27	33	22	79.2	1	141	56.17
Text messages	31	32	47	18	13	74.6	1	141	52.91

Section 3: List of types of information which the on-site staff would like to exchange while on-site

Table 3.1: The frequencies and number of answers of the information required on construction-site

Types of information	Not important at all	Not important	Neither	Important	Very important
A. Requests for information	6.4%	5.7%	13.5%	28.4%	46.1%
	9	8	19	40	65
B. Subcontractor information	4.3%	12.1%	33.3%	27.7%	22.7%
	6	17	47	39	32
C. Task allocation	5.7%	2.1%	19.1%	29.8%	43.3%
	8	3	27	42	61
D. Quality assurance	5.7%	8.5%	12.1%	17.0%	56.7%
	8	12	17	24	80
E. work directory	5.0%	5.7%	22.0%	33.3%	34.0%
	7	8	31	47	48
F. Field observations	4.3%	2.1%	20.6%	31.9%	41.1%
	6	3	29	45	58
G. Monitoring progress	5.7%	9.9%	14.2%	24.8%	45.4%
	8	14	20	35	64
h. Work package information	5.0%	8.5%	31.9%	27.0%	27.7%
	7	12	45	38	39
i. Monitoring health and safety on site	7.1%	11.3%	10.6%	19.9%	51.1%

	10	16	15	28	72
j. Daily report	4.3%	6.4%	19.9%	34.0%	35.5%
	6	9	28	48	50
k. changing orders	4.3%	21.3%	30.5%	18.4%	25.5%
	6	30	43	26	36
l. Delay recording	2.1%	9.9%	22.7%	35.5%	29.8%
	3	14	32	50	42
m. Quality inspections	4.3%	9.9%	11.3%	24.1%	50.4%
	6	14	16	34	71
n. Reporting violations	5.0%	10.6%	27.0%	27.7%	29.8%
	7	15	38	39	42
o. schedule updates	4.3%	6.4%	22.0%	37.6%	29.8%
	6	9	31	53	42
p. accident reporting	5.7%	7.8%	14.9%	29.1%	42.6%
	8	11	21	41	60
q. Site investigation	5.7%	2.8%	20.6%	30.5%	40.4%
	8	4	29	43	57
r. Exception reporting	5.0%	16.3%	13.5%	22.0%	43.3%
	7	23	19	31	61
s. equipment management	5.0%	5.7%	34.0%	20.6%	34.8%
	7	8	48	29	49
t. Site diaries	1.4%	9.9%	39.0%	21.3%	28.4%
	2	14	55	30	40
u. Material Management	6.4%	5.0%	16.3%	34.0%	38.3%
	9	7	23	48	54
v. On-site accounting of operatives/visitors	5.0%	11.3%	43.3%	22.0%	18.4%
	7	16	61	31	26
w. Activity Duration	2.1%	10.6%	27.0%	31.2%	29.1%
	2	15	38	44	41

x. Defect management	2.1%	8.5%	39.0%	30.5%	19.9%
	3	12	55	43	28
y. View a drawing	4.3%	5.0%	7.8%	27.7%	55.3%
	6	7	11	39	78
z. Weekly report	7.8%	9.2%	33.3%	28.4%	21.3%
	11	13	47	40	30
aa. Annotate a drawing	3.5%	4.3%	37.6%	25.5%	29.1%
	5	6	53	36	41
bb. Monthly report	9.9%	17.0%	36.9%	22.7%	13.5%
	14	24	52	32	19
cc. Read methods statement	5.0%	5.0%	32.6%	17.7%	39.7%
	7	7	46	25	56

Table 3.2: The weight of the information required on construction-site

Types of communication tools	Not important at all	Not important	Neither	Important	Very important				SI
	0.2	**0.4**	**0.6**	**0.8**	**1**	WI	FI	TR	
A.	9	8	19	40	65	113.4	1	**141**	80.43
B.	6	17	47	39	32	99.4	1	**141**	70.50
C.	8	3	27	42	61	113.6	1	**141**	80.57
D.	8	12	17	24	80	115.8	1	**141**	82.13
E.	7	8	31	47	48	108.8	1	**141**	77.16
F.	6	3	29	45	58	113.8	1	**141**	80.71

G.	8	14	20	35	64	111.2	1	**141**	78.87
H.	7	12	45	38	39	102.6	1	**141**	72.77
I.	10	16	15	28	72	111.8	1	**141**	79.29
J.	6	9	28	48	50	110	1	**141**	78.01
K.	6	30	43	26	36	95.8	1	**141**	67.94
L.	3	14	32	50	42	107.4	1	**141**	76.17
M.	6	14	16	34	71	114.6	1	**141**	81.28
N.	7	15	38	39	42	103.4	1	**141**	73.33
O.	6	9	31	53	42	107.8	1	**141**	76.45
P.	8	11	21	41	60	111.4	1	**141**	79.01
Q.	8	4	29	43	57	112	1	**141**	79.43
R.	7	23	19	31	61	107.8	1	**141**	76.45
S.	7	8	48	29	49	105.6	1	**141**	74.89
T.	2	14	55	30	40	103	1	**141**	73.05
U.	9	7	23	48	54	110.8	1	**141**	78.58

V.	7	16	61	31	26	95.2	1	**141**	67.52
W.	3	15	38	44	41	105.6	1	**141**	74.89
X.	3	12	55	43	28	100.8	1	**141**	71.49
Y.	6	7	11	39	78	119.8	1	**141**	84.96
Z.	11	13	47	40	30	97.6	1	**141**	69.22
AA.	5	6	53	36	41	105	1	**141**	74.47
BB.	14	24	52	32	19	88.2	1	**141**	62.55
CC.	7	7	46	25	56	107.8	1	**141**	76.45

Section 4: The factors that may challenge the use of mobile computing within the construction industry

Table 4.1: The frequencies and number of answers of barriers to the adoption of on-site mobile computing in construction

	Not important at all	Not important	Neither	Important	Very important
A.	10	9	40	46	36
	7.1%	6.4%	28.4%	32.6%	25.5%
B.	5	14	51	42	29
	3.5%	9.9%	36.2%	29.8%	20.6%
C.	7	12	34	50	38
	5.0%	8.5%	24.1%	35.5%	27.0%
D.	7	21	49	39	25
	5.0%	14.9%	34.8%	27.7%	17.7%
E.	10	9	22	58	42
	7.1%	6.4%	15.6%	41.1%	29.8%
F.	9	27	25	33	47

	6.4%	19.1%	17.7%	23.4%	33.3%
G.	8	7	30	44	52
	5.7%	5.0%	21.3%	31.2%	36.9%
H.	12	14	53	38	24
	8.5%	9.9%	37.6%	27.0%	17.0%
I.	9	20	54	33	25
	6.4%	14.2%	38.3%	23.4%	17.7%
J.	18	7	17	42	57
	12.8%	5.0%	12.1%	29.8%	40.4%
K.	8	24	35	44	30
	5.7%	17.0%	24.8%	31.2%	21.3%
L.	10	22	21	51	37
	7.1%	15.6%	14.9%	36.2%	26.2%
M.	6	10	42	47	36
	4.3%	7.1%	29.8%	33.3%	25.5%
N.	5	17	42	35	42
	3.5%	12.1%	29.8%	24.8%	29.8%
O.	23	15	53	19	31
	16.3%	10.6%	37.6%	13.5%	22.0%
P.	9	27	49	39	17
	6.4%	19.1%	34.8%	27.7%	12.1%
Q.	9	17	42	35	38
	6.4%	12.1%	29.8%	24.8%	27.0%
R.	9	4	32	31	65
	6.4%	2.8%	22.7%	22.0%	46.1%
S.	9	10	23	37	62
	6.4%	7.1%	16.3%	26.2%	44.0%
T.	8	11	54	36	32
	5.7%	7.8%	38.3%	25.5%	22.7%
U.	10	10	27	45	49
	7.1%	7.1%	19.1%	31.9%	34.8%
V.	6	9	38	29	59
	6.4%	4.3%	27.0%	20.6%	41.8%
W.	8	16	25	49	43
	5.7%	11.3%	17.7%	34.8%	30.5%

Table 4-2: The weight of the barriers to the adoption of on-site mobile computing in construction

Types of communication tools	Not important at all	Not important	Neither	Important	Very important				SI
	0.2	**0.4**	**0.6**	**0.8**	**1**	WI	FI	TR	
A.	10	9	40	46	36	102.4	1	**141**	72.62
B.	5	14	51	42	29	99.8	1	**141**	70.78
C.	7	12	34	50	38	104.6	1	**141**	74.18
D.	7	21	49	39	25	95.4	1	**141**	67.66
E.	10	9	22	58	42	107.2	1	**141**	76.03
F.	9	27	25	33	47	101	1	**141**	71.63
G.	8	7	30	44	52	109.6	1	**141**	77.73
H.	12	14	53	38	24	94.2	1	**141**	66.81
I.	9	20	54	33	25	93.6	1	**141**	66.38
J.	18	7	17	42	57	107.2	1	**141**	76.03
K.	8	24	35	44	30	97.4	1	**141**	69.08
L.	10	22	21	51	37	101.2	1	**141**	71.77
M.	6	10	42	47	36	104	1	**141**	73.76
N.	5	17	42	35	42	103	1	**141**	73.05
O.	23	15	53	19	31	88.6	1	**141**	62.84
P.	9	27	49	39	17	90.2	1	**141**	63.97
Q.	9	17	42	35	38	99.8	1	**141**	70.78
R.	9	4	32	31	65	112.4	1	**141**	79.72
S.	9	10	23	37	62	111.2	1	**141**	78.87
T.	8	11	54	36	32	99.2	1	**141**	70.35
U.	10	10	27	45	49	107.2	1	**141**	76.03
V.	6	9	38	29	59	109.8	1	**141**	77.87
W.	8	16	25	49	43	105.2	1	**141**	74.61

Appendix F: The Publication

1. Association of Researchers in Construction Management (ARCOM) Doctoral Workshop

Using a Mobile BIM based Framework to Enhance Information Provisioning Support in HealthCare Projects.

[1]Naif Alaboud, John P Cooney and Aziz Zeeshan.

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Abstract: This paper investigates the relevance of mobile BIM in health care projects theoretically. The research will present health care and its design and construction aspects, utilising building information modelling and its technologies. The literature review identifies and highlights how BIM is utilised within a healthcare environment and gives a brief account of how this process has been implemented, with case study overview. Moreover, the review also indicates and discusses any advantages and disadvantages this process has within such a scenario. From this, the paper discusses the relevance of Mobile BIM for better information provisioning, information flow and decision making. Conclusions are drawn about the future impact of emerging mobile BIM technologies to enhance construction processes.

Keywords: Building information modeling, cloud system, health care, mobile computing.

1. Introduction

In recent years, the construction industry has come under increasing pressure from its clients to improve its productivity and to address communication and coordination challenges that often result in projects missing their golden triangle (i.e. cost, time and quality) targets. Also, new demands have been put in place on construction projects because of increasing complexity of design, sustainability, health and safety and other increasingly stringent regulations. Rapid uptake of building information modeling technologies has resulted in major changes in organisational structure, processes and technology uptake within construction organisations. While BIM is defined as “the provision of rich, integrated information-from conception through design to construction and demolition of a building over its life cycle”, Eastman (2008), industry is still in early stages to fully materialise life-cycle information management benefits offered by BIM. This paper focuses on implications of BIM uptake on healthcare design and construction. Section 2 discusses how BIM has come into being, and how it is being utilised within various sectors of the construction industry, particularly within healthcare. Section 3 reviews relevance of mobile technologies and parallel developments in cloud-computing, intelligent interfaces to ensure better connectivity of field personnel in existing workflows and access to information stored in BIM databases. The final section draws conclusions about possible future impact on construction processes.

2. Use of BIM in HealthCare Design - Literature Review

BIM "represents a migration in the architectural design field from two dimensions to three dimensions by creating intelligent, multi-dimensional building models" Reddy (2007). It is widely proposed to be a suitable method to manage all design and construction issued within current IT orientated building projects and process environments. Thomson and Miner (2007) highlighted the dynamic nature of a BIM platform and how it allows multiple geographically dispersed groups to work collaboratively on projects. Such dynamic collaboration is particularly relevant for health care project which are inherently complex by their very nature.

The effect of building information modeling within healthcare design has been known for quite some time, particularly with emphasis on various stages of design, and how it affects the construction process in the overall project. Ulrich (2000) proposed and looked at the effects of healthcare environmental design on medical outcomes. It focuses on the improvement of healthcare design and suggest various parameters within healthcare outcomes such as noise, sunny rooms and their impact on on patients, multiple occupancy vs single rooms, flooring materials and furniture arrangements. The paper would indicate from its findings, a need for a BIM contingent/process to be considered, which would encompass most if not all factors discussed throughout the text. Barista (2012) identified improved coordination of ultra-complex building systems and ability of real-time visualizations as key advantages of using BIM for healthcare facilities design. Sullivan (2007) highlights advantages of BIM to support various construction processes such as health and safety, planning, constructability and coordination, risk and so forth. He also highlights the benefits of a fully coordinated BIM to reduce risks associated with health care industry projects. Similar views has been expressed by Pommer et al (2010), who have looked upon favorably on relevance of lean construction methods in BIM healthcare design.

Manning & Messner (2008) discussed case studies in BIM implementation for the programming of healthcare facilities. They drew attention to a rising cost of construction and inherent complexity of healthcare construction projects and highlighted the opportunity of BIM-based information and analysis early in the development of healthcare construction project. In a similar study, Pommer et al (2010) highlighted various complexities of healthcare projects particularly related to building systems such as indoor environmental quality, cooling and heating loads, quantity of medical equipment and relevance of BIM to address these complexities.

Chanfeng et al (2007), introduced and presented a case study in developing a space centred CAD tool which gives designers an insight of how to effectively manage information and user requirements during conceptual design. They focused on areas related to healthcare, using BIM within an Alzheimer clinic, paying particular attention to how all design criteria can be stored and shown within building space areas, focusing on how the use of information mediums such as pictures, how photography can be transmitted in an effective way, and suggests it is a good way of remembering a room or structure, as it can be seen like a photograph visually. They also highlight and make an emphasis on what space in a building is and how it affects any or all activities being carried out, including limitations dictated by existing space and surroundings. Oloffsen, Lee & Eastman (2007), discuss a case study relating to the advantages seen by implementing virtual design models for the coordination of elements, such as mechanical, electrical and plumbing (MEP) within a healthcare facility. This discussion brings to the attention the advantages of BIM and how it can be used to integrate the various disciplines such as MEP within healthcare to be coordinated. Particular emphasis was made to how costs could be reduced using this overall process, and the type and level of information that needs to be attained using BIM. Leading from this, benefits of such an appraisal within a healthcare facility are also shown and discussed in a case study presented by Chen, Dib & Lasker (2011). They bring to the attention initially the benefits of building information modelling in healthcare facilities, and indeed do concur with Oloffsen, Lee & Eastman (2007), the importance of this process within MEP. However, they bring to attention its role in the commissioning process and discuss how this is related to the buildings lifecycle, suggesting that commissioning and validation process starts as early in the buildings acquisition process as is possible, and through its lifetime. These benefits looked favourably at the healthcare establishment used to present this case study.

Leite, Akinci & Garret (2009), presented a case study to discuss the identification of data items needed for automated clash detection in MEP design coordination. The authors highlight a similar vain of thought regarding MEP, however emphasis is placed on the use of clash detection within the MEP contingent. It compares a manual method of clash detection using 2D drawings, to a BIM process, and suggests that the BIM process was far more accurate. Rizal (2011), identifies and discusses the challenging roles of clients, architects and contractors through BIM, paying attention to how these disciplines correlate within a BIM environment. Building information modeling has seen to be a very useful and creative tool within the AEC industry and healthcare design, to centralise all information within one model and to be able to see a functionality of the components within such a model. Generally, this process could be seen to have advantages and disadvantages, and are generally seen as;

- Drawing reduction – a continuous 3D CAD model for all stakeholders to view the single model on one central network , Chanfeng et al (2007);
- To improve productivity – time saving measures with centralised information;

- Reduces conflicts and changes during construction – adds value to the project because of minimal errors during production of the BIM model;
- Clash detection – advises the end user of any structural clashes that have taken place or are about to take place, design can be reintroduced into that are of construction;
- Group members should be able to communicate any and all technical developments and design, and be able to implement any changes;
- Be able to assign responsibilities;
- Contractor can use BIM, and have the appropriate software to read drawings either remotely, i.e, from a laptop on site, to full operation and input of information from the main contractors original software and access from a central web server, Chanfeng et al (2007);
- Insurance - design mistakes, errors puts the project out of time and so compensation and/or liquidation damages/ costs could be incurred.

Howell & Batcheler (2005), highlight that lessons were also learned from the early preconception of such systems, within it’s development, and also concurs to what was suggested by Yan & Damion (2007) - “BIM has its flaws”. The points highlighted in their paper are indicated;

- The size and complexity of the files that BIM systems create, Kaleigh (2009) also concurs to this observation, and carries on, for complex projects, the scalability and manageability of a fully loaded BIM project database represents a major challenge;
- Sharing BIM information as drawing files;
- The need for increasingly sophisticated data management at the building object level;
- A contradiction in work process when using a single detailed BIM to try to represent a number of the alternative design schemes under consideration;
- Managing “what if” scenarios for engineering design – Using a single BIM model for building performance modelling (i.e. energy analysis, sun-shade studies, egress simulation, etc.) does not provide the flexibility needed by consulting engineers to conduct a multitude of “what if” scenarios to study alternate approaches and to optimize design alternatives in order to maximize energy efficiency, ensure fire and life safety compliance, achieve structural integrity at minimum cost, etc;
- The expectation that everyone on the project team will adopt one BIM system.

3. Relevance of Mobile BIM to Support Onsite Work

This section discusses relevance of mobile computing with a focus on construction phase of healthcare projects. As identified previously, construction projects are relatively complex in terms of their scale. Sites for major healthcare facilities, such as hospitals are hazardous and dynamic by their very nature. Also, specialist nature of various health-care projects make projects quite information intensive. Key advantage of mobile computing for such large projects include reliable and updated information, decrease time and cost in construction operation, decline in faults, accidents, increase in productivity, better decision-making, quality control, etc.

Fragmented nature of various construction operations coupled with site conditions pose challenges to free flow of information to and from the construction site. Even though in recent years there has been a great deal of automation and use of sophisticated BIM programmes to support design work, benefits of such automation are usually limited to design offices. Out on the construction site, printed drawings are still most prevalent method of communication. Recent developments in the area of broadband wireless technologies, mobile technologies and cloud computing provide tremendous potential to enhance construction management practices by readily providing relevant information to concerned professionals. A key challenge in construction management has always been lack of communication and collaboration between key stakeholders. Developments in technologies and corresponding processes promises to address these challenges by bringing improvements to the whole project starting from initial design to the lifecycle of the facility through an integrated approach to information management. As highlighted by Shen et al (2009), "these technologies provide a consistent set of solutions to support the collaborative creation, management, dissemination, and use of information through the entire product and project life

cycle". The use of mobile BIM particularly for the construction phase will make more improvement to project management mainly by reducing the uncertainty and limitations and overcome the challenges by organising and controlling as-built with as-planned progress in construction project. "The emergence of mobile computing has the potential to extend the boundary of information systems from site offices to actual work sites and ensure real-time data flow to and from construction work sites" Chen et al, (2011). Mobile Computing also plays a key role in management of information generated during a construction project. Construction projects are very information intensive and a typical project generates tens of thousands of documents in the form of drawings, change orders, request for information, etc. For effective communication and coordination, it is important to manage this information flow in an effective manner. Wilkinson (2005) defines 'construction collaboration technology' as a combination of technologies that together create a single shared interface between two or more interested individuals (people), enabling them to participate in a creative process in which they share their collective skills, expertise, understanding and knowledge (information) in an atmosphere of openness, honesty, trust and mutual respect, and thereby jointly delivering the best solution that meets their common goal. Using mobile BIM it is possible to create such a collaborative platform bringing together site-based and office based personnel. Mobile computing technologies provide engineers unprecedented opportunities to innovate the existing processes of construction projects Kim et al, (2011).

However, a lot of recent implementation of mobile technologies within construction has failed. A key reason has been technologies have been implemented without adequate consideration of organizational need and corresponding process change. If technologies are not implemented without corresponding process change, they may automate existing workflows without bringing any tangible process improvement. In his landmark report, Egan (1998) advised construction industry, stating that, “New technologies can simply reinforce outdated and wasteful processes. The change should be approached by first sorting out the culture, then defining and improving processes and finally applying technology as a tool to support these cultural and process improvements” Egan (1998). Thus, for effective implementation of mobile computing and BIM technologies, it is important to understand the organizational and process context prior to implementation of technology.

In order to ensure good alignment between BIM technology and corresponding processes and organisational strategic objectives, it is imperative to explicitly outline how the needs and requirements of the project will be mapped to technical standards, team member skills, construction industry capabilities, and the technologies that will be used. Through the development of this plan, the project team members and project management outline their agreement on how, when, why, to what level (e.g. site supervisor, foreman, worker) , and for which project outcomes BIM modeling will be used Autodesk (2012). Having such plan in place will ensure that there are adequate supporting processes in place to support implementation of BIM technology. Integration mobile construction workers in the BIM workflow and information distribution chain, the decision-makers’ obtains reliable data and real-time from point of work to speed up workflows and enable informed decision making. However, industry needs to overcome various technological challenges to enable smooth workflows. Industry Foundation Classes (IFCs) are currently the key method of data exchange. However, the initial problem with IFCs is that it is not intended to store and carry relevant data for all multi-featured construction processes. Furthermore, not all relevant data can be structured in a single super schema Redmond et al, (2012). This may necessitate learning from experiences in other industries to ensure smoother data flows.

Recent developments in the area of cloud computing can also support uptake of mobile computing. Mobile platforms are limited by their size and memory. By making only relevant bits of information available from the cloud using intuitive interfaces has the potential to further drive uptake of mobile BIM in construction. This will allow construction project information to be much lighter, easily reached from any computers or tablets such as IPad and IPhone, and are easily updated. The function of this system is simply store the project information in the cloud computing and access it by for example, the project team in the field or where and when they want, even without the internet. In the meanwhile, the internet operates with computer and other devices and combined with cloud-based tools which would make data and information more accessible to the staff, yielding key benefits such as cost/time savings, owner satisfaction, improvements in information access, sustainability, team integration and access to BIM visualisation Bringardner & Dasher (2011).

4.Conclusions

The review indicates huge potential to improve current delivery of healthcare projects using mobile BIM technology and processes. The case studies discussed in the review highlight and give an indication of how BIM is being utilised, and suggests any and all impacts this process may have within a healthcare environment. While a key emphasis of existing BIM deployments has been on certain low hanging fruits such as trade coordination and construction documentation, the future possibilities of a multitude of applications using analytical capabilities of BIM technology are enormous. The dominance of VDC and BIM in the design and construction industry will "tip" when it becomes measurably more efficient, productive and profitable to use that project process" Strazdas (2011), has proposed and highlighted that BIM is becoming more "mainstream", and also suggests that, "one expects to build the models with much more information on a systematic basis as time goes on". Parallel developments in the area of mobile computing, cloud computing by providing real-time information and applications to and forth from field personnel. However, it is important to realise uptake of mobile BIM will require industry to address various process and organisational level challenges and take adequate steps to facilitate uptake of improved processes using improve technologies.

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Development of a Framework to Enhance Information Provisioning Support for Site-based Construction Workers in The Kingdom of Saudi Arabia

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Abstract

Construction projects are very information intensive and a typical project generates tens of thousands of documents in the form of drawings, change orders, request for information, specifications etc. For effective construction communication and coordination, it is important to manage this information flow in an effective manner. Recent developments in technologies enable improvements to the construction methods and processes to overcome various communication and co-ordination challenges. In recent years, there is an increasing interest in use of mobile computing and wireless technologies both as a tool and a collaboration concept. With this remarkable growth there is a direct interest in its employment to enhance construction production. With increased computational power available on mobile devices and developments in high bandwidth wireless technologies, it is possible to extend the benefits of various collaboration technologies to the point of work. Construction Industry in Saudi Arabia is growing rapidly with Government financing huge infrastructure projects. However, the industry has peculiar characteristics such as multi-cultural workforce, high level of fragmentation, low education, extreme natural environment and transient nature of construction workforce. This makes implementation of new technologies and improvements in construction processes and practices particularly difficult. This paper focuses on understanding the key challenges in providing timely and relevant information to site-based construction workers particularly site supervisors and site engineers in Saudi Arabia which will help to develop the framework.

Keywords

Construction management, Communication, Mobile computing, Productivity

1. Introduction

The information and communications technologies (ICT) have extensively been applied to address communication and collaboration challenges and to enhance productivity, performance and quality in design and delivery of construction projects. However, the construction industry is still lagging behind other industries such as aerospace and automobile, in terms of deployment of more advanced ICT systems for communication and integrated design and manufacturing. The construction industry has its own characteristics such as the involvement of many participants, the separation between site offices and work sites, and the mobility of construction personnel. Many of construction projects have failed to meet cost, time and quality targets and were marred with poor communication and coordination problems between site-based and office-based staff. In recent years, there has been tremendous development in technologies such as cloud computing, wireless networking and mobile technologies which can assist to improve construction management. Mobile computing can play a key role in management of information generated during a construction project and improvement of the existing process by ensuring right information is delivered to the right person at right time were real-time progress is updated and better decision-making is taken.

However, before engaging this new technology to cope with the construction dilemma, it is essential to address and comply various factors. These issues can be categorised in to the technology itself, its usability, the construction organization and culture. In other words, it’s necessary to explore the interactions between them because they are likely affect the design and the implementation of mobile computing. This paper present a doctorate research that reflects just how mobile computing could be best implemented to enhance on-site construction information in Saudi Arabia for site-based construction workers. Following a description of the study achieved, a model of the key challenges is presented with initial descriptions on its nature. The conclusion is drawn with a short argument on the proposed model.

2. Key construction project management challenges in Saudi Arabia

The Saudi construction industry become the “largest construction sector in the Middle East and remains a 'construction safe heaven' amid both wider political and financial turmoil” (Deloitte & Touche, 2013). “In 2008, the value of capital assets of the building and construction sector was $41,2 US billion dollars, up from about $ 19.9 US billion dollars in 2004, reflecting an average annual growth rate of 19.9%” (MEP, 2012). Furthermore, Figure 1 presents the tremendous growth of the industry which is driven mostly by the government. In recent years, the Saudi’s strong economy reflected on its development plans and large-scale investment that established infrastructure, such as a network of trains and trams, roads, bridges, dams, airports, ports, facilities for electricity and desalination, etc.

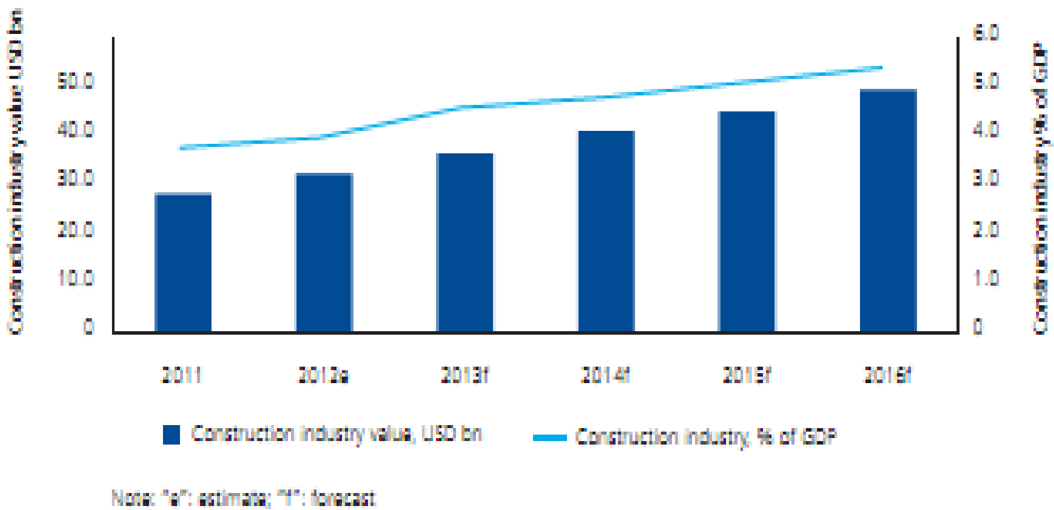

Figure 1: The estimated construction growth in Saudi Arabia (Deloitte & Touche, 2013)

However, with this growth, the industry is facing various challenges as some projects have failed to meet its cost, time or quality targets. Generally, Deloitte & Touche (2013) indicated that the total value of delayed projects estimated by Saudi Arabian contractors in July 2012 is USD 146bn. With regarding to the doctorate research project, the researcher is focusing on the challenges that regarding the construction site. The industry suffers from different kind of delays such poor project management, low labour productivity, communication and coordination problems. These problems are well documented in recent literature (e.g. Alsuliman et al., 2012; Albogamy et al., 2012; Alkharashi and Skitmore, 2009; Assaf and Al-Hejji, 2006).

There is a wide body of literature focusing on productivity improvements on construction sites with a focus on sites in western developed countries. However, there is a great deal of variation between construction sites in Saudi Arabia when compared with Western construction sites characterized by multi-cultural, multi-language, low and semi-skilled labor and very low adoption of technology coupled with heavily subsidized AEC sector, fuelling various process inefficiencies (Alsehaimi, 2011). A recent survey by Sidawi (2012) of construction companies in KSA showed that 89% of respondents are still using traditional communication systems and tools such as fax machines, mobile phones (voice and texts), site visits, weekly/monthly reports and face to face meetings. Sidawi (2012) also found that 93% of survey respondents do not use advance mobile systems and tools, apart from basic use of mobile phones for voice communication. This should be seen in the backdrop of the fact that total population of construction workforce in the private sector is 3.5 million (45.1% of total construction workforce) in 2011 (Saudi Arabian Monetary Agency, 2013).

3. Mobile computing and construction management

As known the construction project characterised as heavy workforce and generate tens of information which needs effective project management. Löfgren (2005) mentioned that part of the poor productivity figures in the construction industry could be explained by the fact that the information needs and communication behaviours in the production at the construction sites are not adequately met. Moreover, managing information in construction is the main success factor for performance. Thus, practical and efficient communication tool is required and targeted by many scholars and practitioners for many years. However, in the construction stage most of the technologies that being used stoped in the site offices. While very few technologies become available to use in the site.

Mobile computing address's a critical area in the hole project which provides great opportunity to extends the boundaries from the site offices to the work sites by connecting those moving personnel's and increasing their mobility. In other words, the potential improvement of using Mobile computing is regarding to "the enhanced mobility of computing devices, which allows users in any location to access and share important construction project information in an efficient manner" (Kim et al, 2013). "firmly believe that mobile computing-integrating mobile devices, wireless communication and mobile services- presents the missing link in Construction Information Technology, thus providing appropriate information flow in the life-cycle of a building product"(Danijel et al, as quoted by Anumba et al., 2012).

This new way of flowing the information influence the project team and force their existing processes of handling the information to change. Kim at el (2013) indicated that the advent of smartphones, coupled with state-of-the-art mobile computing technology, provides construction engineers with unprecedented opportunities to improve the existing processes of on-site construction management. Also, "the adoption of mobile computing devices can make a significant contribution to the ongoing drive for process improvement" (Bowden et al, 2005). The advances in affordable mobile devices, increases in wireless network transfer speeds and improvements in mobile application performance, gives mobile computing technology a powerful potential to enhance on-site construction information management. Furthermore, smartphones are currently fitted with high resolution color touch screen, GPS navigation, gyroscope, wireless communication capability, digital camera, sensors, high-speed data transfer with 4G, etc. These powerful features "enable a new generation of on-site management processes, such as high mobility, location-based customized work orders, real time information exchange, and augmented reality (AR)-based site visualization" (Kim et al, 2013).

4. Research methodology

According to the existing improvements in mobile technology, information systems, wireless connection, etc. Which provide potential chances to mobile computing to be best utilized in onsite construction communication. This research has seven objectives but the critical one is to develop an understanding of key challenges in providing timely and relevant information to site-based construction workers engaged in public sector construction projects within the Kingdom of Saudi Arabia which are explored in a model. In order to develop an information provisioning framework to support information needs of site-based construction workers. In other words, this theoretical model will classify all main factors and their relations, which affect the design and implementation of the framework. Exploring the factors relations as well as validating and evaluating this model will be in the next stage after analyzing the data that collected by the questionnaires and the case studies supplemented by semi-structured interviews and observations. Which will aid to develop several scenarios to demonstrate how the framework of mobile computing can be used to support information needs of site-based construction workers in Saudi Arabia. and how mobile computing can enhance the effectiveness of the construction process for Site supervisors and Site managers.

To successfully meet the objectives of this research, a well-designed methodology was essential. The main research strategy used in this research is constructive research which contains seven steps as shown in Figure 2. Constructive research is supplemented by Case studies (Interviews and Observations) as primary method and Survey Questionnaire as secondary method for data collection. "Constructive research is used to define and solve problems, as well as to improve an existing system or performance, with the overall implication of adding to the existing body of knowledge" (Oyegoke, 2011). It aims at creating solutions for both practical and theoretical problems (Figure 2). Solutions are repeatedly recommended through managerial problem solving techniques over the construction of models, drawings and strategies.

“Constructive research assumes that there are multiple interpretations of reality and the need to understand how individuals construct their own reality within their social context” (Oyegoke, 2011).

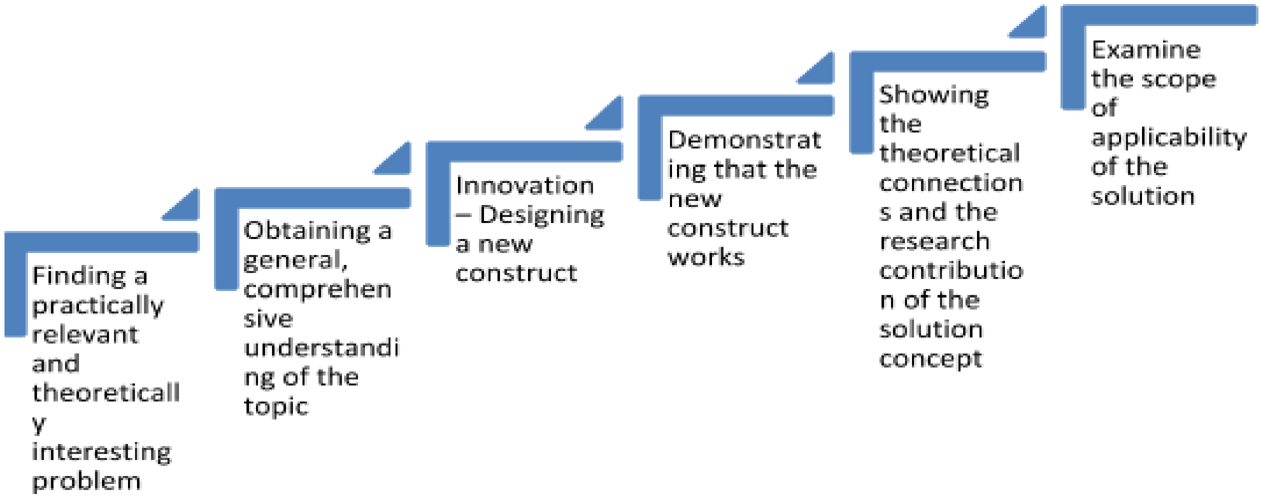

Figure (Key Constructive Research Processes (Oyegoke, 2011 :2

5. Model of key challenges that affect the implementation of mobile computing

After exploring the literature of Saudi construction industry characteristics also investigating literature in the area of the mobile computing application for site-based construction workers, a model is developed in order to understand the situation which will aid to build a framework for practical use of mobile computing. This model identifies the key issues of the technology itself, the construction organization, culture and its usability (Figure 3). The next stage in the research is to explore the interactions between them because they are likely affect the design and the implementation of mobile computing in Saudi Arabia. Generally, with the increasing interest in mobile computing in the construction industry, “it still meets with skepticism from the industry because of the relative lack of supporting data and a lack of understanding of mobile computing devices (Son et al, 2012). In other words, the construction professionals are aware and recognize of the benefits and the usefulness of the use mobile computing technologies in construction site. However, they are clearly unsure how to implement them on their projects and concerned about its complexity (Bowden, 2005; Chen, 2008; Son et al, 2012; Kim et al, 2013).

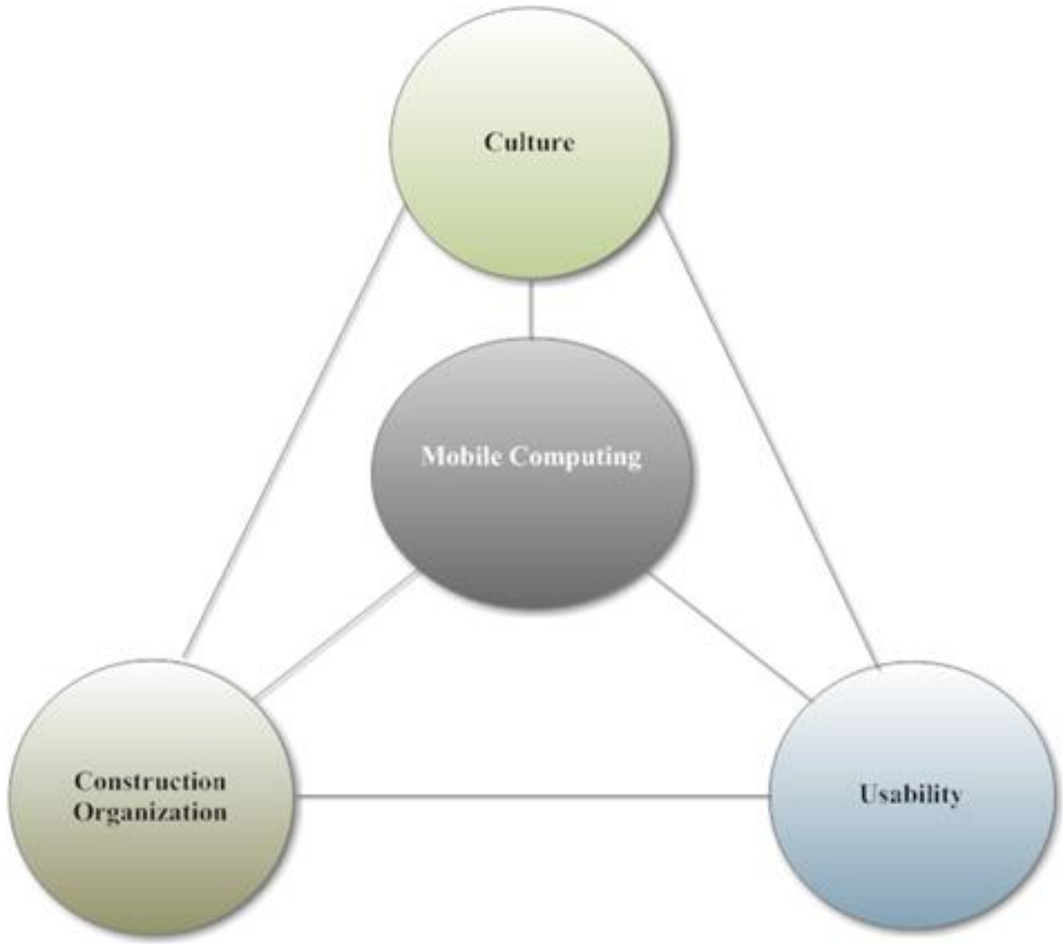

Figure 3: Key challenges that affect the implementation of mobile computing

5.1. The technology challenges and limitations

Frequently, technological complexity is one of the main constraint to the use of mobile computing devices which relatively regarding to the screen size, input difficulties, battery life, etc. Bowden (2005) found that half of the survey respondents believe that they did not think that hand-held computers could be used on site, thought that they would not stand up to the harsh site environment. Moreover, Chen (2008) indicated that there are some constraints regarding to mobile computing such as 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. Furthermore, in case of breakdown or damage to the device, there is possibility that "all the work that had been carried out since the last synchronisation could be lost. Also, with staff working a 8-10 hour day, the inconvenience of running out of battery power whilst out on site could create reluctance to rely on the device" (Bowden, 2005).

5.2. Organisational barriers

Generally, the construction professionals are aware and recognize of the benefits and the usefulness of the use mobile computing technologies in construction site. However, they are clearly unsure how to implement them on their projects and concerned about its complexity (Son et al, 2012; Bowden, 2005; Kim et al, 2013; Chen, 2008). In other words, the success or failure of mobile computing or any technology provided by a firm is depend on the readiness of the staffs to utilise it in executing the tasks. Son et al, (2012) stated that the manager's return on investment in IT is often very low because of employees' refusal to use the IT that is available to them or their reluctance to use it to its full potential. Also, the training is another factor that effect the use of mobile computing. Moreover, strong support by the top management is vital for mobile computing use. Top management may defined as "the individual's perception of the degree to which top management understands the importance of IT and the extent to which top management is involved in the implementation of IT"(Ragu-Nathan et al, 2004 as quoted by Son et al, 2012). Even the technical support by the top management is needed to guaranteeing the utilization. Technical support includes practical aspects of the user requirements such as "specialized instruction, guidance, coaching, and consultation in using technology" (Son et al, 2012).

5.3. Cultural barriers

Generally, different countries have different cultures and different adoptions of IT in construction projects. Which means that construction firms work get affected because they have many employees that come from different countries and cultures that likely tended to work using their routine of work processes and tools. Moreover, Son et al (2012) indicated that the social influence is another barriers for IT use also mentioned that according to the diffusion of innovation theory that established by Rogers (1983), an individual's decision to adopt a new type of technology is influenced by social forces because of the desire to reconcile one's own opinions or behaviors with those of others. Moreover, Bowden (2005) outlined four points regarding to the cultural barriers which are:

- Attitudes towards the devices and I.T. in general could be a barrier, one participant in the usability trials commented "Ought not to underestimate people, could just pick up a telephone instead…".
- The devices were perceived by some participants in the usability trials as a gimmick or a toy, and it was thought that they should only be used when appropriate rather than as standard.
- A lack of awareness about information and communication technologies (Love & Irani, 2001) and the lack of exemplars demonstrating its successful use by others (Anumba, 1998).
- A lack of IT literacy amongst site-based personnel is commonly cited as a barrier to the implementation of IT on construction sites (Coble & Baker, 1994, Picken, 2001)

5.4. Usability challenges and limitations

Kim et al (2013) stated that the data input and output method of a mobile computer has an impact on the users usability which effect the information process on construction sites and should represents the information efficiently and effectively according to the user abilities. The data input methods include keyboard, touch screen, camera for picture capture, video recorder, etc. The data output of the mobile computing which depends on the construction information format and the mobile capabilities which displayed generally in two types that are "the screen for the information formats of graphic, text, image, and speaker for verbal communication" (Chen and Kamara, 2011). Generally, The data output effected by the "screen size, visibility and resolution" (Chen and Kamara, 2011). Because of the size and weight of the mobile devise that may become too small to handle with larger hands and heavy to carry. These data input and output methods effect the battery life of the mobile which should be running for a long period of time to support the user when they outdoors on site construction (Bowden, 2005; Kim et al, 2013). Bowden (2005) indicated that when the personnel become too reliant on the device, such that if it were to break down they would have to go back to pen and paper and the necessary protocols would no longer be available. Finally, Son et al (2012) suggested that construction firms and mobile computing device providers should put more effort into making and providing their devices easier to use, which can lead to better beliefs on its usefulness.

6. The conclusion

After all, with regarding to the previous studies, many of mentioned points considered in this research alongside with various aspects such as the users work requirements' and their capabilities', the usability of the mobile application which regarding to the numbers of the involved users with taking in mind the personnel's demand of easy to learn and use also the site environment. Also, consider and determine properly the various conditions and factors that affect the workflow of the construction projects such as culture and the organisational fragmentation of the project. Moreover, Davies and Harty (2013) stated that future study might aid our understanding by guiding the attention to the process and context along with the content and outcomes of similar construction IT innovations undertaken across a variety of project and organisational arrangements. Moreover, the selection of mobile computing should pay attention to the physical features to the site environment such as site rugged condition, water, humidity, dust, crash resistance and have good battery to support users' for long time on sites. Finally, the next stage will be to analysis the collected data to exploring the factors relations as well as validating and evaluating this model. In order to develop an information provisioning framework to support information needs of site-based construction workers. With taking in mind some other demands which for the construction management system for site engineers should meet: (Kim et al (2013)

- The on-site construction management system should be capable of site monitoring to understand the current status of the construction project.
- The system should provide information of work tasks for site engineers to effectively manage construction resources.
- The system should have the function of real-time information sharing to facilitate efficient interaction among construction participants.

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3. Advances in Construction ICT and e-business

Mobile Computing Applications within Construction

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1. Introduction

In recent years, the information and communications technologies (ICT) have extensively been applied to address communication and collaboration challenges and to enhance productivity, performance and quality in design and delivery of construction projects. However, the construction industry is still lagging behind other industries such as aerospace and automobile, in terms of deployment of more advanced ICT systems for communication and integrated design and manufacturing. Construction clients are increasingly demanding shorter construction cycle times, access to up to date information, better value for money and improved quality. Recent advances in Information Communication Technologies in general and mobile technologies in particular offer new opportunities. Samuelson et al (2014) highlighted areas of Information Technology (IT) investment growth within building industry, including document handling, portable equipment/mobile systems, Computer Aided Design systems, Information search via the Internet, Accounting systems, Project management, Systems for technical calculations, Project webs (EDM), Product models/ Building Information Models (BIM), Systems for costing/ cost control, E-commerce, New business models and Virtual Reality.

Given the fact that construction sites comprise dynamic and unstructured work environments and hazardous work settings, it necessitates the use of intelligent ways to support mobile construction workers. In recent years, there have been significant developments in technologies such as information systems, cloud computing, wireless networking and mobile technologies, which can assist to better integrate mobile construction workforce. Recent advances in Mobile Information Technology include improved wireless bandwidth, better quality of service, low cost, higher processing power and battery life, and hardware to support real-time connectivity. These advances enable better data sharing, which has become a trigger for growth in mobile computing.

This chapter reviews evolution and key drivers of mobile computing within construction. This is followed by a discussion on the need for integration between various project stakeholders is highlighted, to ensure smooth flow of information between project participants. Relevant research in the area and case studies on how various construction production management activities are supported using mobile computing is presented. Recent developments in the area of cloud computing and Building Information Modelling and emerging application scenarios in field data collaboration, co-ordination, production support, building handover and facilities management are discussed. A prototype architecture and demonstrator illustrating use of mobile web services, Internet of Things for on-site environmental services monitoring is presented. Conclusions are drawn on future possible impact of emerging mobile technologies on the construction industry.

2. Drivers for Mobile IT Use in Construction

Traditional methods of distributing construction information are labour-intensive and involve lot of manual intervention. These cause delays in key processes such as information gathering, processing and access. Also, there are problems in information redundancy, invalidity and conflicting or clashing data, resulting from manual data handling. This negatively reflects on the construction project, often leading to delays, cost overruns and quality issues, as a consequence of manual data handling. Mobile computing presents the missing link by allowing connectivity between the construction site operations and office-based operations. The potential advantages of mobile computing within construction context include provision of reliable and up to date information, decrease time and cost in construction operation, decline in faults, accidents, increase in productivity, better decision-making and better quality control. Over past few decades, a key focus of ICT developments within construction sector has been on office/fixed desktop-based clients. Mobile computing provides a vital link to better connect majority of the site-based staff to backend systems. This allows site based workers to access and share important construction project information from the point of work.

Construction project execution phase is often characterised by production of massive amount of information, in shape of project data, drawings, change orders, request for information, Health and Safety records etc. This information has to be updated and delivered to construction personnel in a way that supports decision making. Son et al (2012) indicated that mobile computing devices enable the industry to seamlessly and effectively capture and transmit information and eliminate the kinds of errors and delays that are inherent in manual approaches. Kim at el (2013) highlighted how the advent of smartphones, coupled with state-of-the-art mobile computing technology, provides construction engineers with unprecedented opportunities to improve the existing processes of on-site construction management and enable process innovation. Bowden et al (2006) outlined potential advantages of mobile IT within construction, including reduction in construction time and capital cost of construction, reduction in operation and maintenance costs, reduction in defects, reduction in accidents and waste, increase in productivity and predictability.

Innovations in mobile hardware and software development mean that commercially available smartphones are fitted with high resolution colour touch screen, GPS navigation, gyroscope, wireless communication capability, digital cameras, sensors and high-speed data transfer with 4G. These powerful features “enable a new generation of on-site management processes, such as high mobility, location-based customized work orders, real time information exchange, and augmented reality (AR)-based site visualization” (Kim et al, 2013). Also, site supervisors and site managers have the needed information available for them to act and execute the tasks. This enables the participants to have a clear awareness of the current status of the work. Anumba and Wang (2012) summarised briefly the benefits of mobile computing for influencing the decision making:

- Mobile computing enable construction workers, many of whom are often nomadic, to remain connected to their offices while undertaking work at distributed locations.
- Using mobile and pervasive computing technologies, workers can access required from their point of work on as-needed basis.
- The tracking and management of workers at distributed locations is greatly facilitated, as project managers and others can monitor the progress of work in

real time, enabling the re-direction of resources as appropriate to ensure timely completion.

- Distributed construction project team members stand to benefit from improved and more effective communication systems.
- The integration of context-awareness with mobile and pervasive computing technologies enable the timely delivery of the right information/ services to the right person as the right time.
- There is scope for greater efficiency in the delivery of information and services, as there can be tailored to the individual project team members.
- Improved collaboration (in terms of both quality of information exchange and the throughput of collaborative work) can be achieved using mobile and pervasive computing technologies.
- Real-time and context-specific retrieval of information directly addresses the problem of information overload and improves the throughput of project tasks.
- Mobile and pervasive computing technologies offer tremendous opportunities for enhanced training provision for construction workers.
- Tracking mobile construction personnel has major benefits with regard to safety and security of the worker, particularly in hazardous, challenging or remote work locations.

Table 1 provides summary of key benefits of mobile computing as discussed in literature.

Table 1: Summary of mobile computing benefits

The benefits	**Description**	**Authors**
Timely delivery of information	• Seamless and effective capture and information transmission • Awareness of the current status of the work	Chen and Kamara, 2008, 2011 ; Anumba and Wang, 2012; Wang, 2012; Kim, et al, 2011, 2013; Nourbakhsh et al, 2012; Son et al, 2012
Better decision making and reducing	Better decisions are taken because of the reliability and availability of the information from point of work and	Anumba and Wang, 2012

organisation fragmentation	better integration of on-site staff	
Improved working efficiency	This includes better input and processing of information and provisioning of timely information	Bowden, 2006; Chen and Kamara, 2008, 2011; Anumba and Wang, 2012; Kim, et al, 2011, 2013; Nourbakhsh et al, 2012;
Location-based construction information	The task information is associated with the corresponding location information which enabled the construction engineers to easily understand where the tasks	Kim et al, 2011, 2013; Wang, et al, 2012;
User acceptance and perceived performance	The construction professionals perceive the advantages of mobile computing	Bowden, 2006; Son et al, 2012
Increase productivity	The managers can reduce the time of organizing information, and the foremen can be sure that they are executing the work in accordance with the latest information	Bowden, 2006; Chen and Kamara, 2008a, 2011; Anumba and Wang, 2012; Kim, et al, 2011, 2013; Nourbakhsh et al, 2012; Son et al, 2012
Construction Process Improvement	Improving processes can provides construction engineers with unprecedented opportunities to improve	Bowden, 2005; Chen and Kamara, 2008, 2011; Anumba and Wang, 2012; Wang, 2012; Kim, et al,

	the existing processes	2011, 2013; Nourbakhsh et al, 2012; Son et al, 2012).
High mobility of Construction Workers	It provides site engineers and foremen the ability to perform and move between site locations and site offices	Anumba and Wang, 2012; Kim et al, 2013
Tracking and management of workers	Monitoring the progress of work in real time, enabling the re-direction of resources as appropriate to ensure timely completion. Also, safety and security of the worker particularly in hazardous, challenging or remote work locations can be ensured.	Anumba and Wang, 2012
Improved collaboration	In terms of both quality of information exchange and the throughput of collaborative work.	Anumba and Wang, 2012
Enhance training provision for construction personnel	Exploration of new opportunities for training site personnel using emerging technologies such as Augmented Reality	Wang et al, 2012

Table 1 summarised key benefits of mobile computing from construction industry perspective. However, to optimise mobile computing benefits for construction, it is important to explore convergence and synergy between different enabling technologies, to ensure technology is aligned to support construction worker needs. The following section provides a summary of key efforts in this area.

Chapter 9: 3. Evaluation of Utilisation of Mobile Computing on Construction Sites

Using affordable mobile technology such as smartphones, tablets alongside with the latest generation of communication infrastructures such as touch screen, GPS, gyroscope, accelerometer and wireless communication capability, various software applications have emerged in recent years. Kim et al (2013) categorised previous studies of mobile computing for construction into five different areas:

1. Development of a framework or platform to demonstrate how mobile computing should be used for construction.
2. Mobile computing as a tool for identification or general construction management.
3. Mobile computing for defect management.
4. Mobile computing for safety or disaster management.
5. Development of specific features of mobile computing.

The above provide a useful categorisation of mobile computing research. However, given fast pace developments in the area, including developments in context aware computing, augmented reality, use of drones for data collection and LIDAR, such categorisation needs to be constantly reviewed. Nourbakhsh et al (2012) provided a summary of key published research on mobile application development within construction sector (Table 2). The review indicates wide range of applications in use, to serve wide range of objectives.

Table 2: Developed mobile application systems for on-site information management (Nourbakhsh et al ‹2012)

System function	Tools	References
Field inspection	PDA	Cox et al., 2002
Inspection system, checklist and reference system, position check system Progress monitoring system	PDA	Kimoto et al., 2005
PDA- and RFID-based dynamic supply chain management system	PDA, RFID	Wang et al., 2007
Progress monitoring through monitoring	PDA	Vilkko et al., 2008

status of precast concrete		
They proposed a model for process of selecting mobile computing technologies in construction	PDA	Chen & Kamara, 2008
Defect management: capturing digital images or movies of the defects, annotating a note regarding each defect, defining the locations of the defects, as well as sending the above information to an off-site database to be accessed from the design office	Nokia N80	Dong et al., 2009
(1) Construction equipment finder (2) Access to safety-related information	iPhone	Irizarry and Gill, 2009
A mobile collaboration tool which was functioned as a phone, fax, e-mail and canvas fordrawings.	N/A	Venkatraman and Yoong, 2009
A self-managed information system on mobile phone for informing workers to facilitate job openings	Nokia N73	Yammiyavar and Kate, 201

Chen and Kamara in (2011) presented a model for exploring mobile computing with information management on sites. There are two aspects of the model, including independent and dependent factors. The dependent aspects include mobile computers, wireless network and mobile application, perceived as essential components of mobile computing. Three independent factors include the user, construction information and construction site, that are fundamentals to govern mobile computing use in construction context. The independent elements help understand the construction environment in which mobile computing will be applied to manage information and determine the design of mobile computing systems (Fig 1) (Chen and Kamara, 2011).

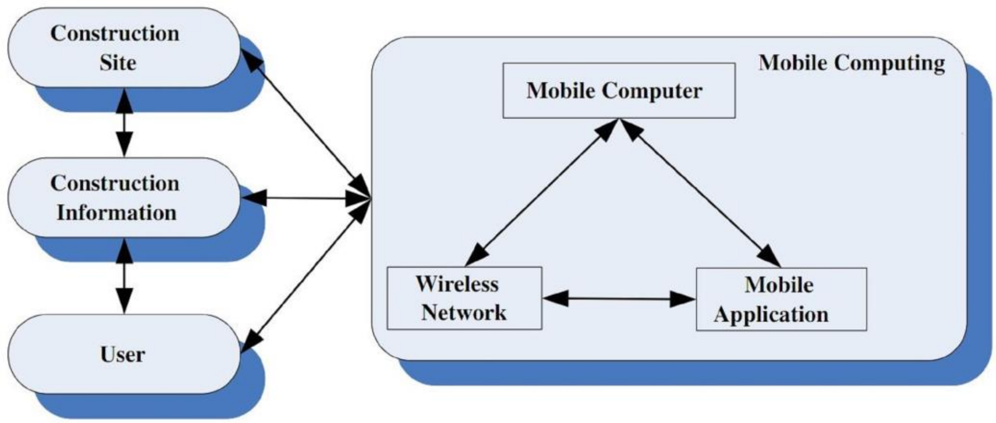

Figure 3: The application model for exploring mobile computing with information management on construction sites (Chen and Kamara, 2011)

Kim et al (2011) proposed a location-based construction site management system, using a mobile computing platform. The developed system utilises iPhone SDK (Software Development Kit) and is designed for the site management and construction drawing sharing. Kim et al (2011) stated that the system showed a strong potential to implement a truly ubiquitous and intelligent construction site, by improving the current level of data sharing and communication practice in the construction industry. The system was further developed and tested on a real construction site. Bringardner and Dasher (2011) presented an adopted mobile computing system implemented in renovation of Dallas-Fort Worth Airport. The system was designed mainly to access the drawings, specification and other project documents and view the BIM model. Also, it constituted use of commercially available platform and low cost apps, cloud computing for storing and entering the project data, synchronisation of Project Information Clouds and remote access of BIM models through tablet devices. Key benefits of the approach included low cost, much lighter, accessibility from tablets and desktops and more easily updated. As a result, the adopted system saved one to two hours per day for each user because they can look at the drawings while standing at the issue. Nourbakhsh et al (2012) developed a construction mobile application, comprising 13 information groups (Figure 2). The functionality of the proposed application is first entering the user recognition page to authorize personnel’s to get through the system. Different individuals access different sections of the application based on their roles and responsibilities. For example, supervisor managers can view, edit, and approve the information, but site managers can only view and edit. Davies and Harty (2013) presented 'Site BIM' which is a Table computer based application, to access design information and to capture work quality and progress data onsite. The system consisted of five components (Figure 3) including Document Management System, to allow for upload and receiving of information such as drawings. Coordinated 3D BIM models were located on site servers, maintained and coordinated by Contractor Document Controllers. Due to capacity limitations, BIM models was split into floors and/or zones for each building. These two systems were linked with the Site dBase, which is a commercial product consisting of a 3D BIM model viewer and database functionality (Progress, Compliance and Defects) to allow characteristic metadata to be linked with objects in the model and to use these relations for illustration, searching and reporting objectives. The system was implemented and test on a large hospital construction project in the United Kingdom. The result showed waste reduction and significant savings in spending on administrative and in co-ordinating staff time.

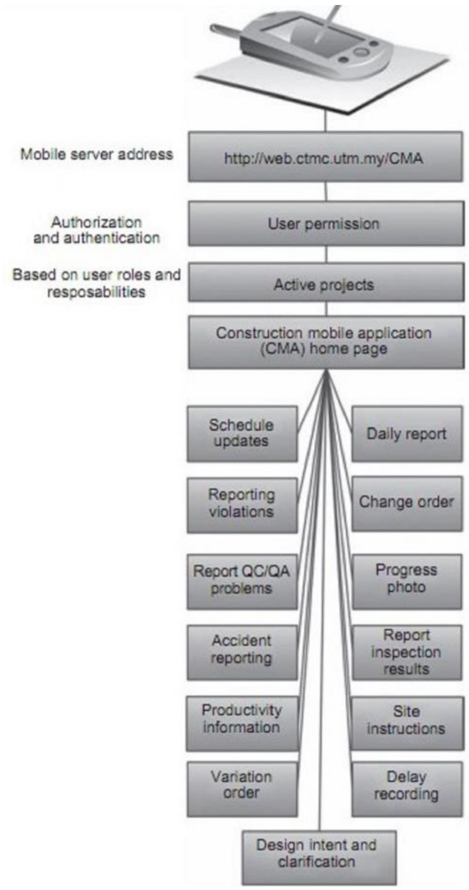

Figure 2: Construction Mobile Application (Nourbakhsh et al, 2012)

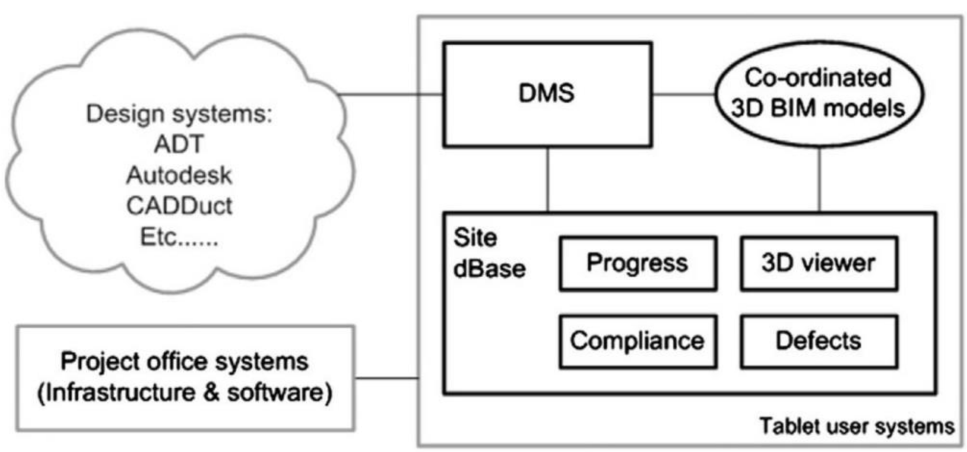

Figure 4: The components of SiteBIM systems (Davies and Harty, 2013)

4. The Barriers and Challenges of Using Mobile Computing in Construction Site

There is a broader recognition that mobile computing can play a key role in management of information generated during a construction project and in construction process innovation. However, lack of supporting data and an understanding of hardware platforms give rise to some scepticism (Son et al, 2012). Many construction professionals are unsure on how to implement mobile applications on their projects and concerned about its complexity (Son et al, 2012; Bowden, 2005; Kim et al, 2013; Chen, 2008). Furthermore, mobile computing has four key technical constraints including limitation of computational resources resulting from size and weight restriction, vulnerability to loss or damage concerning security considerations, variety of connectivity issues and reliability, and limited battery power (Chen, 2008). However, these limitations may be overcome due to rapid improvements in technology. Saidi et al (2002) outlined two key barriers to the use of mobile computing in construction including a) limitations of mobile devices including screen size, screen visibility, processing capability, and input method and b) construction industry characteristics including physical jobsite conditions (such as temperature, humidity, dust, etc.) and organisational issues such as the industry's fragmentation and low risk tolerance.

Moreover, several research studies have explored and discussed some of the emerging technology barriers and challenges which may affect the data exchange (Chen and Kamara, 2011; Anumba and Wang, 2012; Wang, 2012; Son et al, 2012; Nourbakhsh et al, 2012; Bowden, 2005). These barriers and challenges can be categorised into two broad categories of technological and organisational barriers.

Frequently, technological complexity is one of the main constraint to the use of mobile computing devices, related to screen size, input difficulties, battery life, etc. Kim et al (2013) stated that the data input and output method of a mobile computer has an impact on the usability, which affect the information process on construction sites and should represent the information efficiently and effectively according to the user abilities. Size and weight of the mobile device may become too small to handle with larger hands and heavy to carry.

Also, there are various construction industry specific barriers for using mobile computing. In general, the construction professionals are aware and recognise the benefits and usefulness of the use mobile computing technologies on construction sites. However, they are clearly unsure how to implement them on their projects and concerned about its complexity (Son et al, 2012; Bowden, 2005; Kim et al, 2013; Chen, 2008). Such complexities arise because of the very nature of mobile computing which involves integration of various peripheral technologies, coupled with constraints of mobile devices such as limited size, interface etc. The success or failure of mobile computing or any technology provided by a firm is dependent on the readiness of the staff to utilise it in executing the tasks. Son et al, (2012) stated that the manager's return on investment in IT is often very low because of employees' refusal to use the IT that is available to them or their reluctance to use it to its full potential. Also, the training is another factor that affects the use of mobile computing. Moreover, strong support by the top management is vital for supporting mobile deployment. The extent to which top management is involved in IT implementation and understands its significance could make a difference. Even the technical support by the top management is needed to guaranteeing the utilization. Bowden (2006) outlined four points about the cultural barriers which include:

- Attitudes towards the devices and I.T. in general could be a barrier;
- The devices were perceived by some participants in the usability trials as a gimmick or a toy, and it was thought that they should only be used when appropriate rather than as standard.
- Lack of awareness about information and communication technologies and the lack of exemplars demonstrating its successful use by others.
- Lack of IT literacy amongst site-based personnel

5. Emerging technologies

Mobile computing has a large number of applications, across multiple disciplines. Emerging areas of growth include ubiquitous and location based services, augmented reality, sensor networking and profiling technologies. Key emerging technologies are discussed below.

- *Location-Based Services* refers to applications that utilise the user/object location knowledge to provide relevant information and services, with mobile phone working as a cursor to connect digital and physical world. An accurate and timely identification and tracking of construction components are critical to operating a well-managed and cost efficient construction project. Wide range of indoor and outdoor location tracking technologies can be used for facilitating construction operations.
- *Ubiquitous Computing* is an emerging paradigm of personal computing, characterised by the shift from the dedicated computing machinery (requiring user's attention e.g. PCs) to pervasive computing capabilities embedded in everyday environments. The vision of the ubiquitous computing requires a wide-range of devices, sensors, tags and software components to interoperate. The benefits of ubiquitous computing are perceived as ubiquitous access to information, seamless communications based on wireless technologies and computer mediated interaction with the environment through sensing, actuating and displaying. The key functionality to implement the ubiquitous computing functionality include context-awareness (the ability to capture user context such as location and other sensory data), service discovery (finding available service providers in a wireless network), awareness of user requirements/preferences (making the user's desires known to other service providers), user-interface design (touch screen, voice input, speech output, etc.), the ability to match user requirements to services; and machine learning to improve performance over time, and adapt to better meet the user's needs. Relevance of the ubiquitous computing for the construction industry lies in the fact that these technologies have the potential to make construction collaborative processes and services sensitive to the data available in the physical world enabling a wide range of applications from field data collection, to materials management, to site logistics.
- *Sensor Networks* – In the construction industry, sensor networks can be used to monitor a wide range of environments and in a variety of applications, including wireless data acquisition, machine/building monitoring and maintenance, smart buildings and highways, environment monitoring, site security, automated tracking of expensive materials on site, safety management and many others. In future, using different hardware technologies such as wireless communications, smart materials, sensors and actuator, it will be possible to add additional context dimensions, allowing for better mapping of the physical and virtual world.
- *RFID* –The term RFID describes technologies that use radio waves to identify individual items using tags. Being radio based, it has a non-line-of-sight readability. RFID technologies can be used for a wide range of applications to enhance construction processes including materials management, location tracking of tools/equipment, safety and security, supply-chain automation, maintenance and service provisioning, document control etc.

- Augmented Reality Technologies: This involves visualisation of built environment using photographs and videos captured through mobile devices, to develop a better understanding of spatial constraints. Mapping the camera pose (e.g. location, orientation, and field of view) allows photos captured from a mobile device into common 3D coordinates, to allow virtual exploration of the site through integration with building data. This creates an augmented reality environment, where building data is superimposed on photo or video being captured through mobile device. The augmented photograph or video could be used to present key information to relevant site staff and to facilitate communication and reporting processes.
- Profiling technologies allow the delivery of personalised information to users, based on their profile and device capabilities. A W3C working group recommends the use of the CC/PP (Composite Capability/Preference Profiles) (CC/PP, 2003) framework to specify how client devices express their capabilities and preferences to the server that originates content. Using the CC/PP framework, information collected from the terminal can be tagged with relevant context parameters (such as location and device-type). It is also possible to enable selection and content generation responses such as triggering alarms or retrieving information relevant to the task at hand.

6. Application of Mobile Web Services for on-site Environmental Surveillance

The intensity of environmental impact of construction activities is significant and many of the activities throughout a construction project life cycle are not environment friendly (Tam and Tam, 2006). Although construction activities contribute to soil pollutions, key areas of concern with regards to environmental impact of construction activities include air, water and noise pollution (Gray, 2015). Similar observations were made by Zolfagharian et al. (2012), who after interviewing industry experts identified 'Noise Pollution', and 'Dust Generation by Construction Machinery' as the most risky environmental impact on construction sites.

Construction sites generate high levels of dust, resulting from use of materials such as concrete, cement, wood, stone, silica. Dust also results from activities such as land clearing, operation of diesel engines, demolition, burning, and working with toxic materials and this can carry for large distances over a long period of time (Gray, 2015). Construction dust is classified as Particulate Matter (PM_{10}). PM_{10} has an aerodynamic diameter of 10 microns or less and this allows such matter to be carried deep into the lungs where it can cause inflammation and a worsening in the condition of people with respiratory illness, asthma, bronchitis and even cancer. Noise pollution resulting from the construction sites result from use of vehicles, demolition activities and use of construction machinery such as pile drivers, cranes, rock drills, mixing machinery and other types of heavy duty equipment (Chen and Li, 2000). Noise also results from other site based activities. Excessive noise is not only annoying and distracting, but can lead to hearing loss, high blood pressure, sleep disturbance and extreme stress. Research has shown that high noise levels disturb the natural cycles of animals and reduces their usable habitat.

These adverse impacts have led to a growing realisation of the need to better implement environmental protection initiatives at construction sites. To ensure effective implementation of environmental management systems in the project development, periodic environmental surveillance through inspections and environmental quality monitoring should be conducted from time to time where non-conformity is identified (CIRIA, 2010, Environmental Protection Authority of Australia, 1996, Jabatan Kerja Raya Malaysia, 2013). Further corrective action and prevention action in the context of continuous improvement should be undertaken accordingly, to address the issues. However, existing approaches rely on manual and paper based inspection methods, which are time consuming, labour-intensive, produce limited information and can involve deficiencies and discrepancies (Vivoni and Camilli, 2003, Kim et al., 2008, Damian et al., 2007, Mohamad and Aripin, 2006, Harun et al., 2015). Recent developments in mobile computing, sensor computing and the Internet of Things provide vital building blocks to enhance existing processes, leading to delivery of concise, accurate, timely and usable environmental information, crucial in the surveillance activities.

6.1. ENSOCS Prototype

This Section presents a system architecture and prototype of a mobile web-based environmental information system. The system aims to improve environmental checking and the correction process, by providing a tool for environmental enforcement officer for managing their environmental surveillance activities on construction sites, to enhance their decision-making capabilities. This prototype application demonstrates the “Internet of Things” concept, where the smartphone plays an intermediary role between environmental management teams, ‘things’ (wireless sensor networks and a weather station) and the Internet. The interactions between them have resulted in enrichment of and speedy information, enhancement in the delivery of reports, and enables the alerts of environmental non-compliances.

The proposed system was designed and developed for Internet browsing through a smartphone and works together with telemetry sensors (air and noise) and wireless weather station, to provide real-time environmental data monitoring, to support environmental surveillance undertaken by the inspection officer. The proposed approach demonstrates the interrelationship between activities and pollution in an innovative way, when compared to conventional paper-based methods. While maintaining the concept of a checklist, users may take a note of environmental observations using web forms. For air

(PM_{10}) and noise (dBA) pollution, users can confirm their observational findings by referring to data transmitted by telemetry sensors in real time. Wireless weather station would also provide the indication of the potential polluter by providing the weather conditions (dry/wet) and wind speed and directions. In addition, in any events of non-compliance due to the readings of air and noise parameters exceeding the threshold, early warning alert system is enabled through Short Messaging System (SMS).

For the purpose of prototype demonstration and evaluation, previous researches argue that participants involved in a controlled laboratory setting may not experience the potential adverse effects that are caused by changing and unpredictable network conditions and other environmental factors (Zhang and Adipat, 2005, Kjeldskov et al., 2005). Thus, robust environment will enable realistic assessment of users' acceptability, as it is directly applicable to a mobile environment. Due to these reasons, ENSOCS has been deployed in a real-life construction project, alongside direct engagement with practitioners as evaluators. The set-up of the ENSOCS system comprised one Smart-Cities sensor node, one weather station, one sensor gateway and one Internet-ready laptop. System architecture is illustrated in Figure 4. ENSOCS architecture follows the common four-layer structure of the Internet of Things (IoT) (see Fig. 4), with details of each layer presented as below:

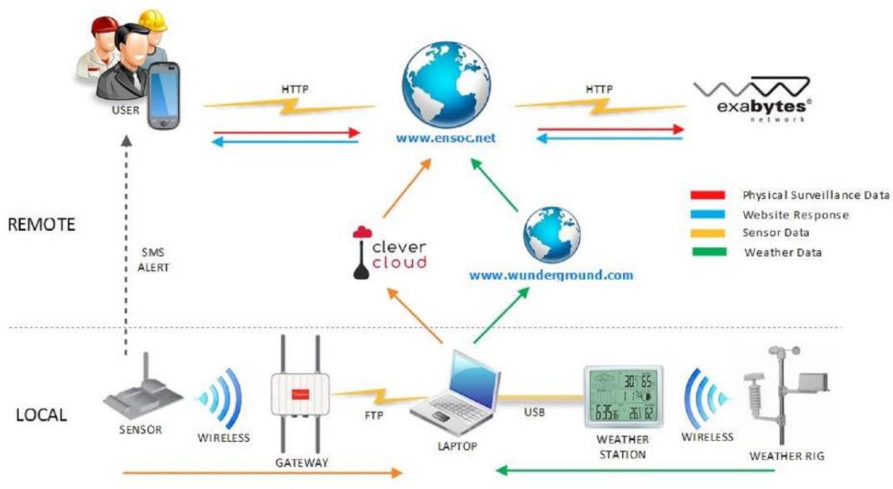

Figure 5: The ENSOCS Architecture

Key layers of the architecture are explained as below:

a) Sensing and Control Layer – This include the Wireless Sensor Network for capturing the reading of PM_{10} concentrations and noise levels and the weather station to obtain weather conditions data. The Wireless Sensor Network delivers the Short Messaging System (SMS) to the users as an early warning alert in events where the reading of PM_{10} concentrations and noise levels exceed or nearly exceed the threshold. Users may take a note of their environmental observations using web forms in the ENSOCS, which is accessible via the smartphone. Built-in smartphone GPS and WLAN are also being used for the determination of the current location of the user;

b) Networking Layer – This includes Wireless Local Area Network (WLAN) and Local Area Network (LAN) to provide connectivity between sensing and control layer and middleware layer;

c) Middleware Layer – This includes the server system which processes the location data gathered from the built-in smartphones' GPS, the sensor data, the data input from the user and the weather data. The server then intelligently maps the right information and services from the servers available in the system. The server systems of the ENSOCS prototype consist of the MySQL Database server and the web server.

d) Application Layer – This includes the mobile client, which allows for input from the user and, at the same time, allow for receiving the Short Messaging System (SMS), while ENSOCS mobile web-based environmental information system will display the environmental observation reports, data from the wireless sensor network (WSN), weather station data and location coordinates from the built-in smartphone GPS.

Smart Cities sensor node and the weather rig were separately placed inside an enclosure and powered by an external power supply connected to the solar panels. This allowed for installation of both units in an outdoor environment. For security reasons, they were installed at a secure location on a construction site, which was well guarded and monitored by construction personnel. The Smart Cities sensor node and weather rig were put in a location 1.4m above the ground and at a position of 4m from the construction hoarding and approximately 6m from the nearest sensitive receptor. The installation took about 1½ hours.

Smart Cities sensor node was equipped with XBee-ZigBee-Pro wireless radio communication, to enable communication with the sensor gateway within a distance up to 7 kilometres. Whereas for wireless weather station, the weather data is transmitted every 48 seconds to the Weather Station from the weather rig via the radio frequency of 915Mhz within a distance of 300 feet (without any obstacles in the open field). Both Smart Cities sensor node and weather station make measurement and periodically sends the results to the server application for further analysis and database storage. ENSOCS mobile web-based environmental information system then collects information from the sensor node and weather station and displays the reading of data on the system dashboard (see Fig. 5).

Figure 5: The Display of Weather Data, Air and Noise Data on ENSOCS' Dashboard

Besides the display of the real-time sensor and weather station data, ENSOCS mobile web-based environmental information system also provides the web form (Figure 6) to enable the user to record their environmental observations, while conducting the environmental surveillance. The integration between observations and real-time data would provide holistic view of the environmental problems at site. For instance, the environmental inspector may feel that the mufflers and noise-shielding were not working effectively during his environmental surveillance. However, only with the support of the real-time noise data would help to justify the findings and permits environmental inspectors to issue out the environmental surveillance report to address the non-compliance on the construction noise control.

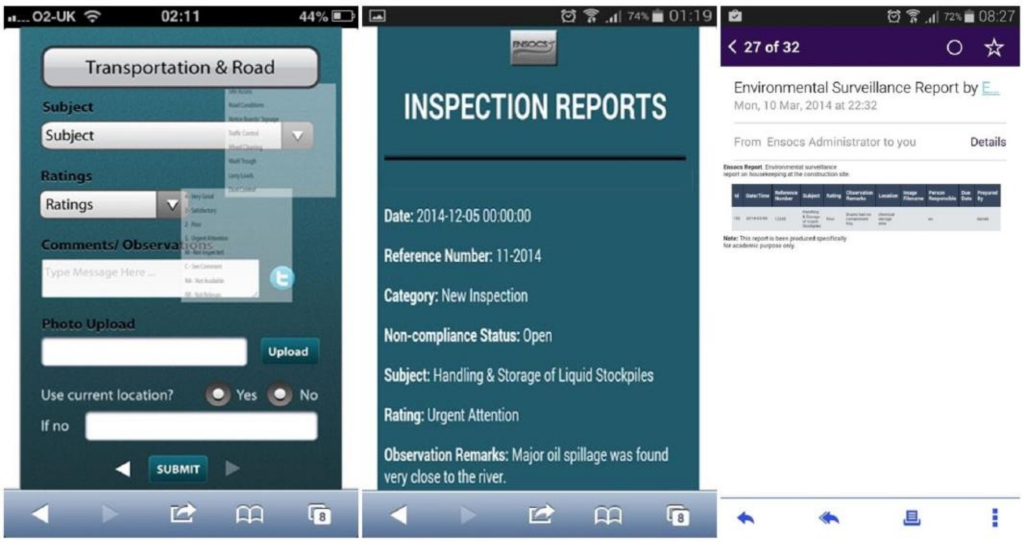

Figure 6: The Web Form (Checklist) and the Sample of a Surveillance Report (Left: Online report; Right: Emailed report) of ENSOCS

The above case study demonstrates that the concept of a mobile environmental information system is feasible, and emerging technologies opens up huge potential to provide support for environmental surveillance on construction sites in real time. The validation process confirmed relevance of prototype demonstrator for supporting site based operations, for accelerating information delivery and for enhancing decision making capabilities through services provisioning and real-time environmental quality monitoring. However, need for further work to better align prototype system to take account of prevailing industry standards in field environmental management were identified.

Chapter 10:7. Conclusions

Given the mobile and dynamic nature of construction production work, there is a need to integrate advances in mobile computing in the work environment to provide user-friendly and mobile access to construction product and production process. There are several issues that must be considered in utilising mobile computing regarding mobility, application abilities, services, integration of current systems and inputs and output methods. This is important to accommodate site personnel requirements and behaviours in the diversified construction site environment. Mobile computing system needs to be considered, applied and managed, while recognising the end user needs. Also, any deployment of mobile IT must follow a careful study of existing processes and organisational requirements, to ensure better alignment of technology to business processes. There is need to redesign existing information system to help achieve higher values of information integration and smooth information flow between site and office based operations. However, given significance of mobile computing for construction, necessitates appropriate investments in research and development, by both industry and academia.

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