

**THE APPLICATION OF MOBILE WEB AND
DEVICES FOR ENVIRONMENTAL
SURVEILLANCE ON CONSTRUCTION SITES IN
MALAYSIA**

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SITES IN MALAYSIA**

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ABSTRACT

Environmental surveillance on construction sites requires environmental information that is concise, to-the-point, timely and usable. However, physical surveillance and traditional environmental monitoring (measurement) are challenging, time consuming, labour-intensive and can involve deficiencies and discrepancies. Technology based surveillance provides an alternative, but with this kind of surveillance it is often difficult to demonstrate a connection between any pollution detected and a specific source in some circumstances. Thus, physical environmental surveillance (observation/walk-through inspection) still remains important but some improvements can be made to it by adopting technology based surveillance. This situation creates an opportunity for deploying an information system which capitalizes on the advantages of the Internet of Things, so that decision makers can obtain an accurate and up-to-date view of their environmental management issues and status.

The aim of this research was, therefore, to set out to investigate the potential for a mobile environmental information system as a part of the Internet of Things technologies for environmental surveillance on Malaysian construction sites. Design Science Research (DSR) has been chosen as the philosophical approach and case study as the research method were adopted for this research in order to achieve its objectives. A literature review on construction environmental management and mobile environmental information management was undertaken, followed by engagement with environmental experts in order to obtain detailed information requirements and to identify user needs. These details were analysed and brought about the formulation of the system design goals, along with a conceptual model, which concluded in the development of the functional specification, the system architecture and the prototype development. The prototype system was demonstrated and evaluated interactively by construction environmental management teams, both in the UK and Malaysia.

The main achievement of the research comprises the analysis of the needs required in a mobile environmental information system, the development of functional specifications and the demonstration and acceptance of the concept by practising construction environmental management teams. The research concludes that the concept of a mobile environmental information system is feasible, realising that it has greatly improving the task performing process as well as enhancing the flow of communication and reporting environmental surveillance activities on construction sites in nearly real time.

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DECLARATION

This thesis is presented as an original contribution based on Doctorate of Philosophy research at University of Salford, Salford, United Kingdom and has not been previously submitted to meet requirements for an award at any higher education institution under my name or that of any other individuals. To the best of my knowledge and belief, the thesis contains no materials previously published or written by another person except where due reference is made.

.....(Signature)

Aizul Nahar Bin Harun

..... (Date)

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LIST OF ABBREVIATION

3D	3 Dimensional
3G	The third generation of mobile telecommunications technology
4G	The fourth generation of mobile telecommunications technology
5G	The fifth generation mobile networks
A-GPS	Assisted Global Positioning System
API	Application Programming Interfaces
ASIC	Application Specific Integrated Circuit
BSI	The British Standards Institute
CEMP	Construction Environmental Management Plan
CO	Carbon Monoxide
dB(A)	A Continuous A-weighted Sound Pressure Level
DO	Dissolved Oxygen
DPI	Dots per Inch
DSP	Digital Signal Processor
DSR	Design Science Research
EDGE	Enhanced Data rates for GSM Evolution
EIS	Environmental Information Systems
EMS	Environmental Management System
FPGA	Field Programmable Gate Array
GIS	Geographic Information System
GDC	General Design Cycle
GPS	Global Positioning System
GPRS	General Packet Radio Service

Green IS	Green Information Systems
GRID	Global Resource Information Database
GSM	Global System for Mobile Communications
HCI	Human Computer Interaction
IA	Information Architecture
ICT	Information and Communication Technology
INECE	International Network for Environmental Compliance and Enforcement
IMPEL	The European Union Network for the Implementation and Enforcement for Environmental Law
IoT	The Internet of Things
IS	Information Systems
IT	Information Technology
ITU	International Telecommunication Union
LAeq	Long-term Average Sound Level
LAeq,T	Long-term Average Rating Level
LBS	Location Based Service
MCMC	Malaysian Communications and Multimedia Commission
MEIS	Mobile Environmental Information System
MMS	Multimedia Message Service
NCR	Non-compliance Report
NFC	Near-Field Communication
NO ₂	Nitrogen Dioxide
NZDIS	New Zealand Distributed Information System
O ₃	Ozone
Pb	Lead
PC	Personal Computer

PDA	Personal Digital Assistant
PDCA	The Plan-Do-Check-Act Model
PM10	Particulate Matter
PPI	Pixels per Inch
RESCATAMEE	Environmental Friendly Urban Traffic Management
RFID	Radio-frequency Identification
ROI	Return on Investment
SMS	Short Message Service
SO2	Sulphur Dioxide
SOP	Standard Operating Procedures
TAM	Technology Acceptance Model
TSS	Total Suspended Solid
UCD	User-centred Design
UNEP	United Nation Environment Programme
Un-Habitat	United Nation Human Settlement Programme
W3C	The World Wide Web Consortium
WAP 1.0	Wireless Application Protocol 1.0
WLAN	Wireless Local Area Network
WPS	WiFi Positioning System
WSN	Wireless Sensor Networks

CHAPTER 1. INTRODUCTION TO THE RESEARCH

1.1 RESEARCH BACKGROUND AND MOTIVATION

The construction industry creates and provides facilities for human activities and social development as well as creating an economic spin-off. However, construction activities often have significant impacts on the environment in terms of energy and resource consumption, waste generation, pollution and damage to biodiversity and natural habitat (Bourdeau, 1999, CIRIA, 2010, Environmental Protection Authority of Australia, 1996, Perbadanan Putrajaya, 1998, Environmental Protection Department of Hong Kong Government, 1996, Chen and Li, 2000, Tam et al., 2006). These adverse impacts have led to a growing realisation that there is a need for the implementation of environmental best management practices upon construction sites (Perbadanan Putrajaya, 1998, CIRIA, 2010, Environmental Protection Authority of Australia, 1996).

All planning and management activities require information. An environmental management team uses information to reconcile competing interests (i.e. environmental policy co-ordination) and to support development decision-making (i.e. policy implementation). They confront issues on a daily basis that require prompt and decisive notifications, communications and responses (United Nations Human Settlements Programme (UN-HABITAT), 2008). Environmental surveillance, in particular, requires accurate information from unique locations in space and time to be delivered to the right person, at the right time, and in the right place. Subsequently, by using that information, immediate sound decisions and reactions can be made by the right person in the same manner. However, the tools available to decision-makers in order to influence development towards environmental sustainability are limited (United Nations Human Settlements Programme (UN-HABITAT), 2008).

Information Systems (IS) research under the theme of Green Information Systems (IS) research has reacted to this challenge. Recently, the role of information technology (IT) for environmental sustainability has received wide attention from both academics and practitioners because IT plays a crucial role in environmental related issues (Bose and Luo, 2011). Green IS for environmental sustainability refers to activities which minimize the negative impacts and maximize the positive impacts of human behaviour

on the environment through the use of IT and IT-enabled products and services throughout the product life cycle (Boudreau et al., 2008, Jenkin et al., 2011, Elliot, 2011).

Many research projects have looked at the concept of Green IS. Such research studies have looked at many areas such as a computer-based scoring method for measuring the environmental performance of construction activities (Shen et al., 2005, Sai On Cheung et al., 2003), the application of integrated RFID, GPS and GIS technology for construction materials and waste management (Li et al., 2005, Razavi and Haas, 2011, Lu et al., 2013), integrating the web and wireless sensor networks for environmental monitoring and providing early warning systems (Jang et al., 2008, Yi, 2006), the development of an environmental management information system (United Nations Human Settlements Programme (UN-HABITAT), 2008) and many other areas which have proved the importance of information systems within environmental sustainability generally and within construction environmental management specifically.

In addition, the advancement of mobile and real-time web technologies (coupled with the growth of mobile communications in recent years) has not only transformed the way in which people and organisations communicate and interact but has also revolutionised the use of IT and IT-enabled products for environmental sustainability. Under the vision of The Internet of Things (IoT), web systems nowadays can be accessed and updated anywhere and anytime through mobile devices connecting to the network (Klopfer et al., 2002). With some additional web configuration it is possible to display real-time information via real-time data streaming from the server (Anghel, 2014). Moreover, the capabilities of such systems have benefited from the advances in wireless sensor networks (WSN) (Heller and Orthmann, 2013, Al-Turjman et al., 2011) and in global positioning system (GPS) technologies (Li et al., 2005). As a result, the integration of these technologies has enabled mobile inspection, real-time environmental data-streaming and the creation of early-warning systems, as well as creating more mobility in the working environment.

The construction industry is an information intensive industry with mobile workers (Bowden, 2005) and, thus, it creates an opportunity for deploying mobile environmental information systems so that decision makers can obtain an accurate and up-to-date view of their environmental management issues and status. This is vital for successful

environmental management initiatives, enabling the organisation to comply with the increasingly more stringent requirements that are enforced by the authorities and which protect the environment.

1.2. PROBLEM DEFINITION

It is widely accepted that Information and Communication Technology (ICT) contributes to the construction industry in supporting tasks, easing communication barriers, speeding up processes and response time and in managing information (Jaafar et al., 2007a, Bowden et al., 2006, Peansupap and Walker, 2005) and, as a result, brings increased effectiveness into the process of construction (Ahmad et al., 2010). But unfortunately, the industry remains behind other industries in many areas and it is still in the relatively early stage of adopting modern internet technology (Klinc et al., 2010, Ahmad et al., 2010, Shen et al., 2010). Adoption is high in the design phase and in facility management but the use of ICT by contractors and site workers is surprisingly low (Löfgren, 2007). As construction work is mainly work out in the field and workers are highly mobile (Mitchell et al., 2006, Vilkkö et al., 2008), the traditional way of doing things is definitely not able to fulfil industry needs. Currently, the delivery of necessary information to a construction site or of collected data back to the office is problematic and slow (Vilkkö et al., 2008).

Additionally, in some countries like Malaysia, research on, and the use of, IT and IT-enabled products for environmental sustainability in the field (including within the construction industry) is low. Tushi et al. (2014) in their review of the literature from 2007 to 2013 have revealed that, based on the number of researches, most studies on Green IS tend to focus on developed nations such as Australia (9), USA (6), UK (2), Sweden (2), New Zealand (1) and The Netherlands (1). A lesser number of studies have reviewed still developing nations such as China (2), Morocco (1), Hong Kong (1), Serbia (1), South Africa (1), India (1) and Bangladesh (1) while research looking at multiple countries has recorded (5) and none at all have focussed on Malaysia. Their findings might be limited to their research methods but, based on the author's 10 years' working experience (2000-2010) as an environmental auditor and manager at a well-

known Malaysian public listed company and subsidiary within the field of construction and oil and gas, it is fair to assume that the use of IT and IT-enabled products, especially for environmental surveillance, among practitioners in Malaysia is still low as people generally only use desktop software and word processing software (e.g. Microsoft Word, Lotus Word, Microsoft Excel, etc.) for the preparation of inspection reports, and use emails and intranets for communication and the sharing of information and documents. Malaysian practitioners currently rely on traditional communication tools (e.g. letters, e-mails, faxes and telephones) and paper-based documents (e.g. the paper form of checklists, plans and manuals) while performing environmental surveillance and, subsequently, manual reporting and record keeping processes e.g. paper-based reporting and filing cabinets. It is envisaged that such current reliance on traditional communication tools will be re-confirmed in this research.

It is also important to note that, although the traditional methods are robust, they are certainly time consuming and challenging (Vivoni and Camilli, 2003). Paper based checklists, plans and manuals, for instance, are difficult to carry in big quantities and offer very limited sources of information at a particular time (Chen and Kamara, 2011). Most importantly, due to its nature, using paper documentation means that practitioners are often unable to react swiftly to a rapidly changing context. Paper documentation can often fail to demonstrate the interrelationship between activities and their consequences in a timely manner. Moreover, the traditional paper based method is labour-intensive and exposed to deficiencies and discrepancies (Vivoni and Camilli, 2003, Kim et al., 2008).

In contrast to the traditional paper based method, the use of mobile devices and real-time data streaming through the Web has the potential to enhance information management and communication processes among participants and play an important role in field data acquisition and validation (Pundt 2002), to detect potential environmental impacts (Xiang-zheng et al., 2002) and, more importantly, to provide warning signs in the areas of construction activities that require immediate corrective action (Cheung et al., 2004). The ability to identify potential environmental impacts as early as possible is vital to any project of any size and scale because “prevention is always better than cure” (Nikander & Eloranta, 1997, cited in (Cheung et al., 2004)). Environmental professionals can easily carry mobile devices with wireless communication connection to field locations for their data collection and validation

tasks. They can easily retrieve data and information from the web servers and/or perform real-time data updates, can exchange data between those servers and can receive a warning sign alert from an environmental sensor on their mobile devices, simultaneously.

Furthermore, the Web also creates an opportunity for the development of an exclusive Knowledge Base for environmental management. This Knowledge Base can include rules, guidelines, best practices, and so forth, for the prevention and resolution of impacts and practices; this knowledge deriving from the practical experience of experts and professionals in the field. This would allow for knowledge sharing and junior environmental staff, in particular, would benefit from this Knowledge Base for their on-job training (Ooshaksaraie et al., 2011).

In addition, the Web would also enable new opportunities for the development of distributed systems that can cross organisational boundaries and provide unique opportunities for teamwork and workflow automation. Independent project participants could share the same system over the Web even if they are using different hardware platforms (Nitithamyong and Skibniewski, 2004).

Therefore, within this research a prototype of a mobile environmental information system (MEIS) was prepared and its application for environmental surveillance on construction sites in Malaysia and the UK was demonstrated. This MEIS is a Mobile Web based information system and is better known as “ENSOCs mobile web”, see www.ensocs.net. It was designed and developed for internet browsing via a Smartphone and works together with telemetry sensors to provide real-time environmental data monitoring; additionally the environmental enforcement officer uses a mobile online checklist and tools to carry out the physical environmental surveillance. It is anticipated that the Web could improve environmental surveillance processes by providing a tool for environmental enforcement officers to assist in managing their environmental surveillance activities and in enhancing their decision-making capabilities.

1.3. AIM, OBJECTIVES AND RESEARCH QUESTIONS

The overall aim of this research is to investigate the potential for a mobile environmental information system for environmental surveillance on Malaysian construction sites. To satisfy the research aim, the following research objectives have been set:

- To review the literature on environmental impacts caused by construction activity;
- To explore the existing practices of environmental surveillance on construction sites;
- To review the existing mobile environmental information systems and their applications as regards environmental surveillance on construction sites;
- To investigate user requirements for the application of a mobile environmental information system for environmental surveillance on construction sites in Malaysia;
- To develop and implement a prototype of the mobile environmental information system for environmental surveillance based on the developed end-user specifications using a combination of ICT tools;
- To evaluate the developed prototype of the mobile environmental information system for environmental surveillance.

In addition, the choice of study design was guided by the research questions as follows:

- What are the dominant impacts from construction activities?
- What are the environmental aspects that can be addressed through surveillance?
- What are the existing methods for surveillance?
- What are the current developments and practices of the mobile web and devices in environmental surveillance?
- What are the information and service requirements that need to be considered in the development of the prototype system?
- How can the mobile web and devices be used for environmental surveillance by environmental personnel to manage on-site information?

- How can these technologies benefit the environmental performance evaluation on Malaysia construction sites?
- What are the barriers project proponents experience by such an implementation?

1.4. RESEARCH PROGRAMME AND METHODOLOGICAL APPROACH

The motivation for this research was derived from the reviews of the disadvantages in the current traditional method and the exploration of the opportunities for the concept of environmental Internet of Things to improve environmental surveillance on construction sites particularly in Malaysia. As this research will investigate the potential of, and demonstrate, a mobile environmental information system as a part of Internet of Things technologies for environmental surveillance, it is in line with the aims of the Design Science Research which is to “produce and apply knowledge of tasks or situations in order to create effective artefacts” in order to improve practice (March and Smith, 1995). Thus, Design Science Research (DSR) has been chosen as the philosophical approach and case study as the research method were adopted for this research in order to achieve its objectives.

Therefore, this research leverages on the research approaches related to the Design Science Research (DSR). In general, the research programme and methodological approaches of the General Design Cycle (GDC), a well-known research methodology for Information System (IS) research particularly for Design Science Research (Vaishnavi and Kuechler Jr, 2007) was adopted for this research. The General Design Cycle (GDC) was introduced Takeda et al. (1990), and in this research, it has been used with the integration of a web development approach into the development phase.

The outline of the research programme and method is presented in Figure 1-1 which shows a summarised graphical representation of the main activities which have been undertaken. The study was divided into five phases, developed iteratively with a number of feedback loops (represented by arrows in Figure 1-1). These phases are (a) awareness of the research problem; (b) suggestion; (c) development; (d) evaluation, and (e) conclusions.

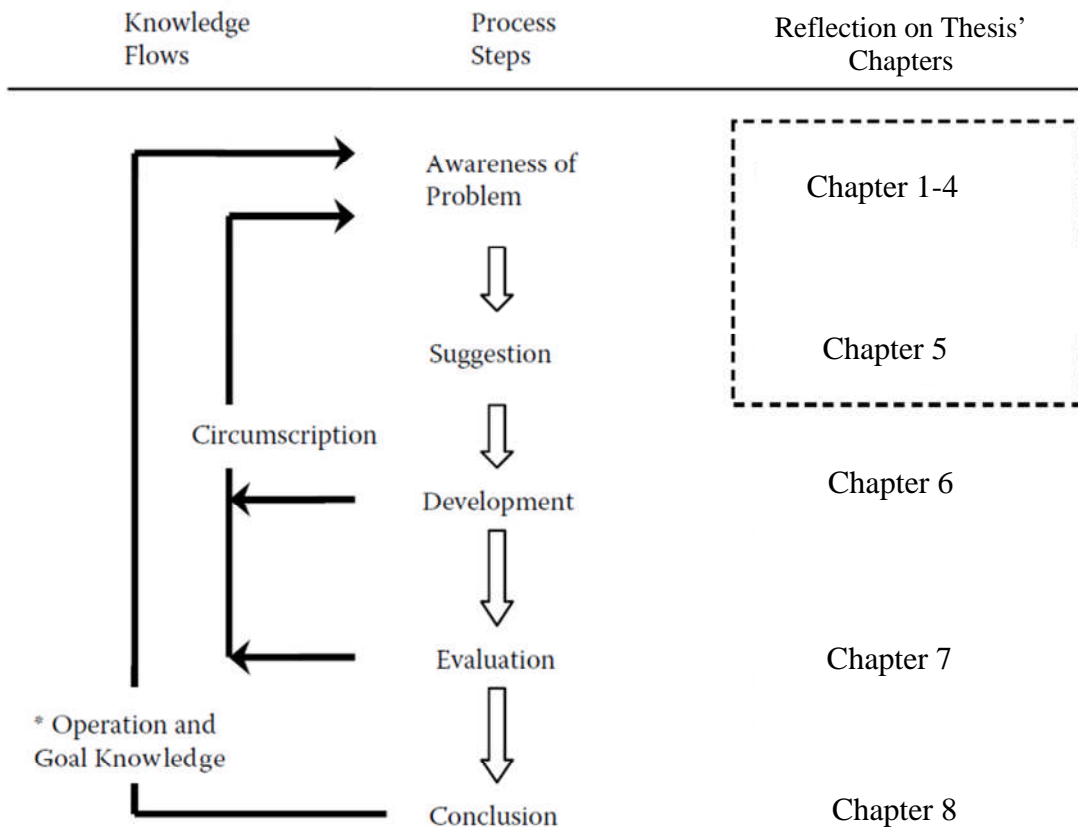


Figure 1-1 The Outline of the Research Programme and Methods

In the first phase, a review of the literature was conducted to define terms and to identify the areas of concern within the research field. This review included the implementation of environmental management at construction sites and the forms and functions of the mobile web and devices. This was a fundamental step to narrow the scope and define the aim of the study. It was also important that the main research focus, objectives, related tasks and activities together with an estimated time period for each of them could be identified in this phase. A structured proposal which contained the objectives and data collection methods and, subsequently, a research programme were then developed.

The second phase involved a review and scoping studies for the research. The review of the literature, technologies and research methodology was carried out with the aims of increasing the researcher's understanding and of clarifying some major issues and outstanding questions in the area of environmental management, information and

communication technologies (ICT) and Information Systems (IS) research. The tentative design of the mobile web and low-fidelity prototype were then prepared.

The third phase was the development phase which involved the whole process of the development of the prototype mobile web. In this phase semi-structured interviews as well as discussion on the web scenarios and demonstration of low-fidelity prototype with selected environmental experts in Malaysia were conducted. This was to provide detailed information about information and system requirements, user needs and the experts' perception of mobile surveillance systems. This provided an insight into the strengths and weaknesses of the existing systems and, at the same time, provided a future direction for the development of the new integrated system. The information collected was then analysed and assisted in the formulation of the system design goals and a conceptual model, which led to the creation of the functional specifications. Then, the system architecture and high-fidelity prototype were developed.

In phase four, the functionality of the high-fidelity prototype mobile web was tested in the field. For this purpose, the prototype was demonstrated to selected environmental personnel both in the United Kingdom and Malaysia. They had an opportunity to test the functions of the mobile prototype by using the mobile devices. The prototype's functionality and usability was evaluated interactively in this demonstration session. The data collected from the evaluation was analysed and discussed. Based on the discussion, the prototype was refined continuously. As a result, the prototype has undergone three refinement processes.

Finally, in the last phase, the findings from the research were summarised and concluded. Based on the findings, further research recommendations were put forward.

1.4.1. THE CASE STUDIES

The United Kingdom (UK) is one of the top-tier performers in the world in the Environmental Performance Index (EPI). It has a long history and experience and continuously demonstrates significant progress in addressing pollution control and natural resource management challenges (Yale University and Columbia University, 2012). Over the last decade, the government has intensified efforts to protect the environment across all economic sectors. This includes support for the Information

Communication and Technology (ICT) innovations that cause products and services within the construction sector to become more environmentally friendly. E-procurement, human-capital development within ICT and the requirement for real-time environmental monitoring are some of the initiatives brought in by the government to strengthen environmental management within the construction industry in the UK (Government Digital Service, 2013). With such support from hard and soft infrastructure, this has made activities become easier to implement in the UK.

Malaysia, on the other hand, is a developing country, a former British colony in Asia. However, since the launch of Vision 2020 by the former Prime Minister Mahathir bin Mohamad in 1991, Malaysia is striving to become a high-income and developed nation by the year 2020 (Islam, 2011, Jaafar et al., 2007a). Most all of the strategic transformation programmes are very much ICT-driven or ICT-enabled and ICT plays a critical role in ensuring their efficient and effective implementation. Starting with the preparation of ICT infrastructures, human-capital development and 'e-Government' under the Multimedia Super Corridor initiative (MSC Malaysia) in 1996, the effort continues under the current Prime Minister Mohammad Najib bin Tun Haji Abdul Razak, one outcome being the government introduction of the National Transformation Policy (NTP) in the 2012 budget.

This continuous effort has resulted in Malaysia having an ICT Development Index (IDI) of 5.04 in 2012 (International Telecommunication Union (ITU), 2013). This makes Malaysia on a par with Brunei and the Maldives as the only group of developing countries in the Asia and Pacific region that have IDI values above the global average. Additionally, a study carried out by the World Economic Forum (WEF) and INSEAD has found that Malaysia can be benchmarked by other ASEAN countries in terms of leveraging ICT to enhance the impacts of ICT in their social and economic environment. In 2012, with an index score of 4.8 out of a maximum score of 7.0, Malaysia is ranked at 29th out of 142 economies; 8th out of 22 Asia Pacific economies and 2nd in ASEAN (Dutta et al., 2012). This demonstrates that Malaysia is always trying to provide a conducive environment for ICT and the country's key stakeholders (individuals, businesses and governments) are ready to accept and use ICT in their activities. Managers of Malaysian construction firms, for example, have been described as being familiar with the use of computers and the internet, are very much exposed to technology/new technology and are interested in adopting new technology (Jaafar et al.,

2007b). Thus, this creates a great opportunity for developing ICT innovations to be applied generally to all Malaysia's economic sectors and to the construction sector in particular.

Like the UK, Malaysia recognises that ICT plays a critical role in ensuring the efficient and effective implementation of strategic transformation programmes in achieving the vision of the future as well as in protecting the environment. The Digital Transformation Programme (DTP), an initiative under the NTP for example, incorporates pure ICT-based projects aimed at providing transformational changes in five broadly categorised dimensions - technological, economic, social, governance and environmental (Wahab, 2012). With regard to the environmental aspect, the 2012 ICT roadmap under DTP outlines wireless intelligence as one of the technology focus areas. Some of the identified key application areas that are poised to drive wireless intelligence include the adoption of wireless sensor networks in agriculture, environmental monitoring, civil infrastructure monitoring and slope and landslides' monitoring, and the use of RFID for wildlife as well as the deployment of M2M in the development of smart cities, smart infrastructure, smart grids, telematics' applications and a wide rollout of 3G and LTE networks (Wahab, 2012).

In line with above mentioned vision and policies put in place by the Malaysian government, this research intends to take advantage of innovations in ICT for environmental management. Moreover, it wishes to support the Malaysia construction industry to leverage more on information and communication technology (ICT), to strive for the highest standard of environmental practices as outlined in the Construction Industry Master Plan 2006 - 2015 (CIMP) and, consequently, to contribute to the success of the overall master plan (CIDB, 2007).

1.5. STRUCTURE OF THE THESIS

This thesis documents the work undertaken in the research project in eight chapters. The content of each chapter can be summarised as follows:

Chapter 1: Introduction to the Research

Firstly, Chapter 1 introduces the research project by providing the general background to the research. It states the research problems. Next the aim and objectives are stated. This chapter also provides a brief description of the research programme and the methodological approach. Finally, it highlights the structure of the thesis.

Chapter 2: Construction and the Environment

This chapter is the first part of the literature review and provides reviews and discussions on environmental management at construction sites. Firstly, it presents the definition of construction and reviews the background information then it describes the relationship between construction activities and the environment. This is followed by a review of the current context of environmental management in construction which includes the environment management lifecycle, environmental surveillance and monitoring. Finally, the environmental information system and the real-time environmental monitoring system will be introduced, described and compared.

Chapter 3: Mobile Environmental Information Systems

This chapter reviews and discusses the development and use of mobile information systems and the enabling technologies. Firstly, it presents definitions of the mobile web and mobile devices. It then reviews the mobile information system concept which is then followed by a detailed discussion on the application of mobile information systems and related works on mobile web applications. The chapter then goes on to discuss the enabling technologies for mobile technologies and communication which include sensor technologies and their integration within the mobile web. Before the end of this chapter, mobile web development approaches will be discussed.

Chapter 4: Research Methodology

This chapter reviews, describes and presents the research philosophies, methodologies and techniques available to address research problems. This leads on to a presentation and description of the philosophy, methodology and techniques employed to achieve the objectives of this research and the justifications for their choice.

Chapter 5: User Requirements Study

The user requirements studies conducted, the conceptual model adopted and the functional specification created are delivered in this chapter. Firstly, the findings from the user studies are analysed and discussed in detail. Then the user requirements are created which lead to the formulation of the system goals. The conceptual model which is adopted is then described and the functional specifications are presented at the end of the chapter.

Chapter 6: Prototype Development

Chapter 6 presents and describes how the prototype system development was conducted. Firstly, the system architecture is introduced, followed by a description of the prototype system development. This is further discussed by explaining the justification for the selection of the hardware, software and the platform for the prototype development. The main features are then outlined and described.

Chapter 7: Prototype Demonstration and Evaluation

The prototype demonstration and evaluation conducted in this research is presented in this chapter. Firstly, functional tests were conducted to test the main features of the application. A description of these tests is followed by presenting and describing the demonstration and evaluation process. Then this chapter focusses on the results and findings from the demonstration and the evaluation which are presented and discussed. Finally, the refinements made to the prototype, based on the findings from the demonstration and evaluation, are further discussed.

Chapter 8: Conclusions and Recommendations

Finally, Chapter 8 concludes this research by summarising the key findings. Since research is an on-going activity, the limitations of this body of work are highlighted. Several conclusions and recommendations for further studies are delivered.

CHAPTER 2. CONSTRUCTION AND THE ENVIRONMENT

2.1. INTRODUCTION AND BACKGROUND

The construction industry is vital in the achievement of the national socio-economic development goals of providing employment, shelter and infrastructure. Construction involves a series of activities that translate an idea on a piece of paper or from someone's head into reality where all the elements, components, materials and finishes will be assembled and will function together to make up part of a building, or a whole building and infrastructure. These activities have assisted in the development of human civilisation but, on the other hand, it has had a negative impact by causing environmental damage (Myers, 2005).

Over the years, the construction industry has been blamed as being a major cause of environmental degradation around the world (Poon et al., 2004) as the activities throughout a construction project's life cycle are not environmental friendly (Tam and Tam, 2006) and very often have had significant impacts on the environment. In general, environmental impacts caused by construction processes can be grouped into three categories which are ecosystems impacts, natural resources impacts, and public impacts (Li et al., 2010). As shown in Figure 2-1, the adverse impacts of construction activities encompass land degradation, poor housekeeping, waste generation, air pollution and odours, water deterioration, noise pollution and vibration, destruction of ecology and historical heritage, consumption of energy and natural resources, and poor vector and disease control, etc.

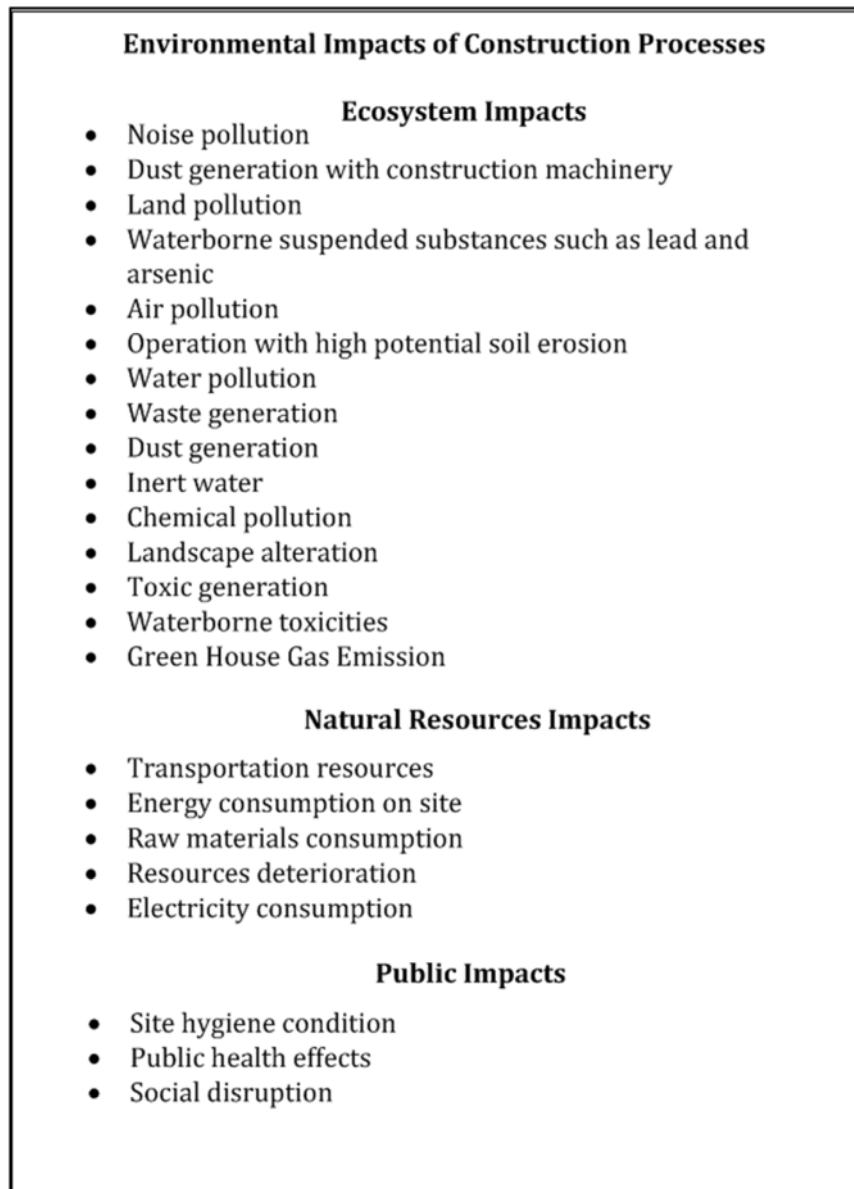


Figure 2-1 Environmental Impacts of Construction Processes (Bourdeau, 1999, CIRIA, 2010, Environmental Protection Authority of Australia, 1996, Perbadanan Putrajaya, 1998, Environmental Protection Department of Hong Kong Government, 1996, Chen and Li, 2000, Tam et al., 2006)

In the context of Malaysia, a recent study by Zolfagharian et al. (2012) has investigated the risk level of environmental impacts due to construction processes. In their structured interviews, a group of 15 construction experts were asked to rate the probability of an occurrence and its severity on the environmental impacts using the five-point Likert Scale to enable them to perform the risk assessment analysis via Risk Matrix. Through

the analysis, the higher score will indicate impacts on the environment are worst compared to others. As a result, the study found that, among the three environmental impacts of construction activities in Malaysia, 'Ecosystem Impacts' have the greatest impact on the environment (67.5% of total impacts) whereas 'Natural Resources' Impacts' account for 21%, and 'Public Impacts' consist of only 11.5%. The results have also demonstrated that 'Transportation Resources', 'Noise Pollution', and 'Dust Generation by Construction Machinery' are the most risky environmental impacts on construction sites in Malaysia.

The results of this study are very important in informing construction players on the negative impacts of construction activities on the environment. Additionally, this study is also useful as it assisted this research to move forward by providing the basis for the researcher to focus on the most risky environmental impacts of construction activities in Malaysia.

2.2. ENVIRONMENTAL MANAGEMENT IN CONSTRUCTION

Such negative impacts, however, can be controlled and reduced through the identification of environmental aspects and impacts of construction activities and the implementation of mitigation measures and site monitoring on a regular basis, e.g through the surveillance put forward by the framework for an Environmental Management System (EMS). Many regulatory bodies have provided some form of comprehensive appraisal on the effect of construction activities on the environment as well as guidelines to control and minimise the impacts (Bourdeau, 1999, CIRIA, 2010, Environmental Protection Authority of Australia, 1996, Perbadanan Putrajaya, 1998).

One such form of environmental management on construction sites is a proactive approach (Environmental Protection Authority of Australia, 1996) that is based on a Plan-Do-Check-Act (PDCA) circle model which originated in ISO standards. Similar to any other organization in any other industry, a construction company must establish an environmental policy in a first stage which includes commitment to the prevention of pollution, carrying out continuous improvement and complying with relevant environmental legislation. The second stage is to identify the objectives and targets

which are related to these commitments; the third stage is to implement and operate the policies, while at the fourth and fifth stage, audits and management reviews have to be carried out periodically to check the compliancy of the standards and the feedback and make changes in the second stage if necessary (Starkey, 1998, cited in (Chan, 2011)).

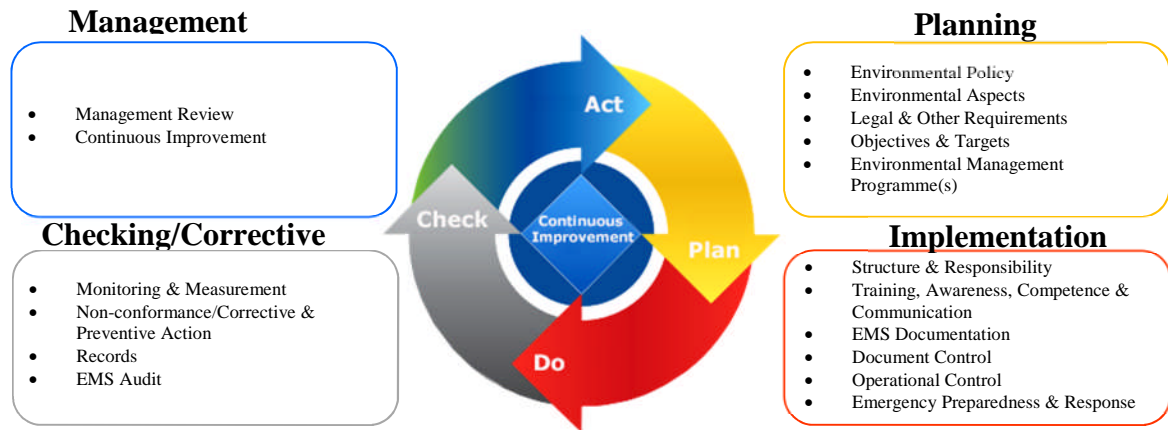


Figure 2-2 The Plan-Do-Check-Act (PDCA) Model for Environmental Management (ISO, 2004)

Such an Environmental Management System (EMS) would provide a framework for an organisation to move towards sustainability. However, it is important to note that the role of “Check” (Checking/Corrective Action) in the PDCA circle model is very important since it acts as an indicator to measure the successfulness of the system and leads to better planning and implementation (ISO, 2004, Tam et al., 2006, International Network for Environmental Compliance and Enforcement (INECE), 2009).

The environmental checking and corrective action are performed to see if the overall targets and objectives of the EMS are being met. According to Martin (1998), the successfulness of the EMS can be determined by comparing the current performance against relevant internal criteria such as organisational practices and guidelines in addition to external standards and regulations. It can be undertaken in various ways and environmental surveillance is one of these (Martin, 1998).

2.3. CHARACTERISTICS OF THE CONSTRUCTION ENVIRONMENTAL MANAGEMENT TEAMS

Generally, regardless of the construction's contractual form, any of construction projects have project teams. A project team consists of an 'in-house' head project manager who carries the final responsibility for the project, one or several assistant project managers, building inspectors and a supporting staff who coordinate aspects such as personnel, finance, quality, the environment, and health and safety issues. Most often the clients' environmental officials coordinate environmental aspects and provide environmental expertise for multiple projects and/or contracts simultaneously. The contractor organisations also have similar structures (Figure 2-3). Depending on the contract size, the environmental coordinators were either located on the project site or at regional divisions. The environmental coordinators' tasks thus varied from providing environmental expertise for a single project to handling multiple tasks (e.g. quality, environmental, and health and safety issues) in concurrent projects.

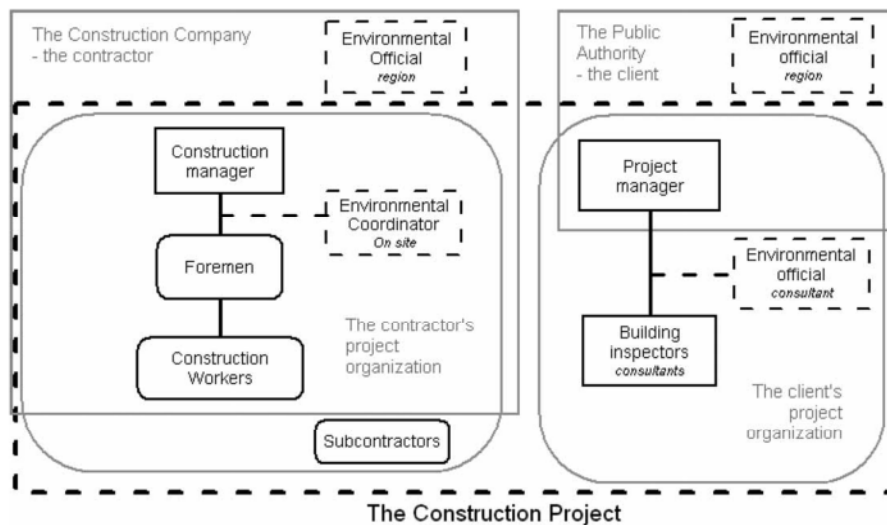


Figure 2-3 Schematic Diagram of the Project Organizations with a Focus on the Actors Involved in the Environmental Discourse (Gluch and Räsänen, 2009)

In terms of environmental communication in the construction projects, Gluch and Räsänen (2009) have conducted a multiple case-study research of four civil engineering projects by using in-depth interviews and field observations. They found that there are three main categories of human mediators of environmental information in construction projects i.e. client representatives, construction managers and the contractor's environmental coordinator. Their findings also showed that: (1) an Environmental

Control Programme, (2) a project plan including corporate environmental policies and routines, (3) various types of report genres, (4) a corporate intranet with EMS and environmental databases, (5) e-mail, (6) the Internet, (7) project meetings, and (8) informal talk and storytelling are the facilitating tools that being used to advance environmental performance.

2.3.1. CLIENT REPRESENTATIVES

Generally speaking, at the project proponent level, the clients' project managers are responsible for monitoring the performance of a project against statutory requirements and the agreed objectives and targets during the construction period (RSK Environment Ltd. (RSK), 2012). As their role concerns controlling rather than operating, clients' project managers do not have to be physically on site but should maintain direct or indirect communication with the construction manager at all times. Client power and visibility are wielded by proxy, i.e. through building inspectors, who are the main translators of information between clients and contractors. These inspectors are consultants with no formal environmental responsibilities or training yet they possess a mandate to enforce action. Their power and visibility are strengthened by the fact that their attendance on-site is associated with assessment and control. The clients' environmental officials have little or no visibility on-site nor do they wield direct influence on environmental practices and decisions in the projects. Their role seems to consist solely of administrative tasks ministered from within the client organization.

2.3.2. CONSTRUCTION MANAGERS

As in most construction projects, there is a strict chain of command which means that all action points have to pass through a construction manager before implementation. The construction manager should possess prodigious knowledge of the project because he is the one who is responsible for the co-ordination of project activities and making day-to-day decisions at the operating level.

For environmental issues, the construction manager will work together with the site environmental representative and the environmental coordinator in coordinating and managing all the environmental activities. The managers will refer to the findings

obtained from the surveillance and to the audit programme undertaken by the site environmental representative and the site environmental officer as they are the key personnel who are directly involved in managing and coordinating environmental activities on-site on a weekly and daily basis (Parsons Brinckerhoff Ltd (PB), 2012).

According to MVV Environment Devonport Limited (MVV) (2012), the responsibilities of the Construction Project Manager are as follows:

1. Management of the works in accordance with all statutory requirements, best practice guidelines and the requirements of the Construction Environmental Management Plan (CEMP);
2. Co-ordinating Procurement, Project Control, Quality Assurance, Environmental Safety and Health, Training, Construction planning activities at the Head Office and Site by following predetermined procedures;
3. Suspension of site work in a specific area or areas should the environment or the health and safety of personnel or the community be potentially at risk;
4. Resumption of works after corrective actions have been completed satisfactorily;
5. Handling all incoming correspondence from various agencies such as the suppliers, sub-contractors and local authorities; and
6. Suspension of individuals from the site where disregard for the CEMP has been identified.

2.3.3. THE CONTRACTOR'S ENVIRONMENTAL COORDINATOR

Due to their rather high visibility on-site and to their access to many sources of environmental information in the relevant contexts (the project, the regional organisation and the environmental staff organisation), the Contractor's Environmental Coordinator acts as a filter of the environmental information to and from the project. The Contractor's Environmental Coordinator assumes the responsibility of implementing the CEMP at the Project Site under the supervision of the Project Manager (Parsons Brinckerhoff Ltd (PB), 2012). Environmental checking and corrective action such as surveillance and internal audits will be carried out from time to time to ensure that all pollution control measures are effective. The Contractor's Environmental Coordinator will advise the Project Manager of any environmental non-compliance issues reported during the site audits (Parsons Brinckerhoff Ltd (PB), 2012).

He will also be responsible for supervising the implementation of corrective actions for the recorded Non-Compliance Reports (NCRs). The Contractor's Environmental Coordinator will also assist the Project Manager in preparing all environmental management related reports for submission to the relevant agencies.

In addition, according to Parsons Brinckerhoff Ltd (PB) (2012) the responsibilities of the Contractor's Environmental Coordinator include the following:

1. To ensure that monitoring, and implementing the audit programme in detecting, environmental deterioration during the construction work is executed regularly;
2. To implement practical mitigating measures to counter all adverse environmental impacts, as and when necessary; and
3. To ensure that all construction work undertaken is in compliance with all applicable legislative requirements.

2.4. ENVIRONMENTAL SURVEILLANCE

The Merriam-Webster Online Dictionary defines "surveillance" as a "close watch kept over someone or something" whereas Jenness et al. (2007) give a more detailed definition. Jenness et al. define surveillance as "the process of collecting information through watching, monitoring, recording, and processing the behaviour of people, objects and events of interested targets in the sensing environment in order to govern activity". In addition, there is a definition of surveillance which is associated with techniques. Tasaki, Kawahata et al. (2007) state that surveillance can be undertaken through routine physical inspection or patrolling, and/or through an established multi-media network on and around the surveillance's area. Similarly, according to Kirchner (2013) surveillance is an organised assessment of aerospace, surfaces, or subsurface areas, places, persons, or things by "observation", technological devices or other means.

Surveillance activities definitely require and generate information which is directly usable by decision-makers in settling on choices or figuring actions. In handling environmental issues, the United Nations Human Settlements Programme (UN-HABITAT) (2008) recognises that such information should be:

“concise: a decision-maker usually is very busy, and does not have time to assimilate more than a page or two at any given time; to-the-point: the manager wants to know what the information means and what she or he can do with it; timely: if information is not available when decisions are taken, then it serves no purpose; it is better to provide partial information in time, rather than complete information which comes too late; and usable: the information has to be formulated in a way that the intended users can understand and relate to, especially as these users are generally non-specialists.”

2.4.1. OBSERVATION

According to Kirchner (2013), observation is regarded as “physical surveillance”. And Kirchner further defined an observation as “a systematic and deliberate inspection of a person by any means on a continuing basis or the acquisition of a non-public communication by a person not a party thereto or visibly presents a threat through any means not involving electronic surveillance”. Many (such as the public) would also view observation as an ‘inspection’ as meaning some form of site visit by an inspector (Farmer, 2007). Inspection itself however, can be classified as walk-through inspections, compliance evaluation inspections and sampling inspections (International Network for Environmental Compliance and Enforcement (INECE), 2009). Nevertheless, looking back to the original definition of surveillance as presented in this thesis by the Merriam-Webster Online Dictionary, Jenness et al. (2007) and Chen et al. (2008), it can be concluded that observation is a walk-through inspection because it meets the characteristics of watching over people, objects and events without involving interviews with facility personnel, and review and critique of self-monitoring methods, instruments and data, etc. Table 2-1 presents details on a walk-through inspection as well as on a compliance evaluation inspection and a sampling inspection.

Table 2-1 Levels of Inspections (International Network for Environmental Compliance and Enforcement (INECE) 2009)

Levels of Inspection	Descriptions
Level 1: Walk-Through Inspection	This type of inspection is limited to a quick survey of the facility. The inspectors need only to walk through the facility to verify the existence of certain features such as control equipment or a records repository, or to observe work practices and housekeeping. These inspections establish an enforcement presence and can also serve as a screening process to identify facilities that should be targeted for more intensive inspection.
Level 2: Compliance Evaluation Inspection	This level involves a thorough inspection of the facility but does not include sampling. It may include visual observations like those in Level 1; a review and evaluation of records; interviews with facility personnel; a review and critique of self-monitoring methods, instruments and data; an examination of process and control devices, and the collection of evidence of noncompliance.
Level 3: Sampling Inspection	This includes visual and recording reviews of the other inspection levels as well as a pre-planned collection and analysis of physical samples. These inspections are the most resource-intensive.

Regardless of the type of inspection, the International Network for Environmental Compliance and Enforcement (INECE) (2009) acknowledges inspection to be the backbone of most enforcement programmes in the field of environmental management. Inspections are widely used because it is believed that compliance with environmental regulations is increased by conducting more inspections (May and Winter, 1999, Alsharif, 2010).

2.4.1.1. PHASES OF THE INSPECTION PROCESS

According to the International Network for Environmental Compliance and Enforcement (INECE) (2009), there are ten (10) phases within the inspection process. The inspection actually starts with an opening discussion to explain the inspection process to the facility and ends with a closing discussion in which the inspector may make facility managers aware of any violations, prescribe corrective actions and explain the consequences of continuing non-compliance (see Figure 2-4).

However, the steps taken before the opening discussion are also important because key for a successful site visit is the familiarity of the inspector with the current situation, the activities and processes, the history and other aspects of the site to be visited (European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL), 1999). Obtaining appropriate information such as the legal register; the licence of the company and details of the application procedure; the site lay-out and drawings of the plant; the reports and letters, etc. from previous inspections; the aspects of the company's operations which have not been thoroughly investigated and approved during previous inspections, etc. would be beneficial to the inspector in gaining knowledge about the site to be visited. Such knowledge would assist the inspector in being able to assign priorities and producing an inspection plan.

In addition, it is also essential to identify every possible environmental aspect and impact of a particular project. The various environmental aspects each have a number of different impacts on the environment. Environmental aspects here refer to any element of an organisation's activities, products or services that can interact with the environment and may have potentially beneficial or harmful effects on the environment. They may also include discharges and emissions, raw materials and energy use, waste recycling, noise, dust, visual pollution, etc. Thereafter, potential impacts must also be identified and mitigation measures should be prepared accordingly.

The inspector, therefore, will inspect and assess the condition of the mitigation measures installed on site in addition to collecting and analysing documentation, gathering evidence (photographs, samples, etc.) and recording observations on the behaviour and position of pertinent environmental aspects within the surveillance area. The inspector will then organise these observations, evidence and supporting documentation into a report for a review against standards set forth in law. The

inspector is not to interpret the law and make the final institutional or agency determination of compliance, but sometimes he makes independent judgments about whether the facility is in compliance. In addition, the inspector's activities would also include, but are not limited to: observing and documenting observations; sampling, measuring and photographing; coring, drilling and excavating; reviewing and copying records, and seizing equipment, products, materials, or records (International Network for Environmental Compliance and Enforcement (INECE), 2009).

Targeting Inspections

- Random selection of sites from all the identifiable members of a regulated community, frequently referred to as a “neutral inspection scheme”;
- A selection that emphasizes a specific sector of the identifiable regulated community, usually based on enforcement history, potential threat, or other clearly researched criteria;
- A selection based on information received from the public or other external sources such as a tip or complaint, and
- Emergency responses.

Preparation of an Inspection Plan

- This phase entails tasks such as reviewing all available information, contacting everyone who may have relevant information, getting administrative clearances, and making necessary arrangements if samples need to be taken.

Entry into Facility

- Most public agencies seek to obtain consensual entry first. If the entry is denied, they try to explain again why the entry is necessary. If denied again, authorization to enter may be granted by a legal authority.

Opening Conference

- The purpose of an opening conference is to let the facility know what the agency plans to do and why, and also to learn more about the facility operation, plant layout, management structure, plant processes, plant safety, and other information relevant for the investigation.

Collecting Evidence in the Field

- Evidence is anything that provides verifiable information that can be used to establish, certify, prove, substantiate, or support an assertion. It can include physical samples, photographs and copies of facility documents. The two most common methods of collecting evidence in the field are facility walk-throughs and process-based investigations. Interviews are also one of the inspector’s most useful tools for gathering information.

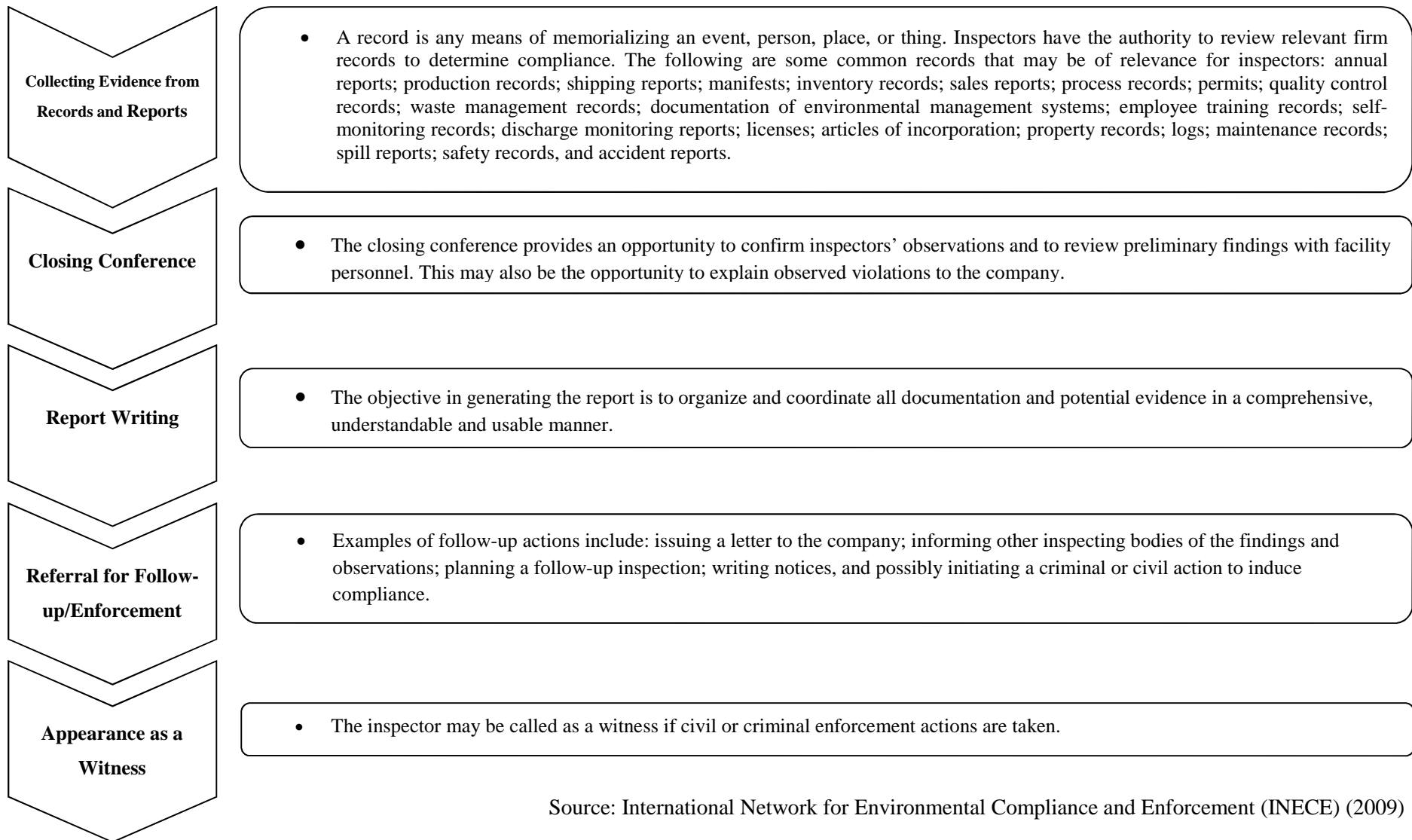


Figure 2-4 Phases of the Inspection Process

2.4.1.2. FREQUENCY OF INSPECTION AND THE AREA OF FOCUS

The inspections may be “routine” (there is no reason to suspect that the facility is out of compliance) or “for cause” (a particular facility is targeted because there is reason to believe it is out of compliance). The frequency of routine inspections depends on the risks posed to the environment by each construction activity or the nature of the site. However, the Environmental Protection Authority of Australia (1996) has proposed a minimum frequency and the areas upon which to focus for routine inspections of construction projects as given in Table 2-2.

Table 2-2 Recommended Minimum Frequency and Area of Focus for Routine Inspection (Environmental Protection Authority of Australia, 1996)

Installation	Possible problems	Frequency	Remedial Action
Drainage	New drainage lines not controlled	At least once every two days in areas where earth-moving is occurring Weekly elsewhere	Install appropriate sediment controls on new drainage lines
Sediment controls, silt fences and traps	Not controlled effectively	Daily in dry weather Within first two hours of a storm Three times a day during prolonged rainfall	Remove sediment from the trap Replace barrier or filter material Redesign installation Improve maintenance

Installation	Possible problems	Frequency	Remedial Action
Haul roads	Dust Soil on paved roads	At least daily	Pave haul roads with gravel or impervious sealant Install wheel wash and rumble grid Manually wash vehicle wheels Increase road cleaning frequency
Cut-off and diversion drains	Water not diverted away from sensitive areas	Weekly	Replace or repair damaged drains Redesign ineffective drains Relocate incorrectly placed drains
In-stream weirs	Ineffective during low flow Release of trapped sediment during	Weekly in dry weather 24 hours before	Evacuate sediment trapped behind weir Clean out behind

Installation	Possible problems	Frequency	Remedial Action
	storms	forecast rain	the weir if filled in at 25% capacity
Stream crossings	Unstable Releasing sediment and soil into the stream	When in use, but no less than weekly	Stop use until installation has been redesigned
Vegetated buffer zones	Accidentally cleared	Weekly	Re-vegetate Review procedures to ensure no recurrence
Retardation and settlement basins and artificial wetlands	Sediments not effectively removed	Weekly	Redesign installation Increase retention times
Stockpiles and bare slopes	Erosion	Weekly	Minimise exposure to run-off and action of wind Ensure stabilisation measures are effective
Un-vegetated areas	Dust	Daily during dry weather	Increase use of water spray on un-vegetated areas

Installation	Possible problems	Frequency	Remedial Action
			Protect un-trafficked areas temporarily with mulch or geo-fabric blanket
Vehicles and machinery	Noise pollution Exhaust gases	Initially when vehicle or machinery is introduced to the site and thereafter monthly	Ensure that mufflers and noise-shielding are effective Ensure that emission controls are effective and motors well maintained
Chemical storage areas	Spills	Weekly	Clean-up contaminated area Improve bunding
Litter controls	Litter on and off-site	Daily on and off-site	Clean-up litter originating on-site Review number and placement of rubbish bins Ensure materials are not stored in such a manner that they

Installation	Possible problems	Frequency	Remedial Action
			<p>could contribute to litter</p> <p>Speak to staff about the litter disposal</p>

2.4.1.3. INSPECTION TOOLS

The inspector needs tools to assist them in performing an inspection. The European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL)(1999) has recommended that a checklist to be used as one of the inspection tools. And according to Canter and Sadler (1997) who have considered twenty two (22) types of tools for the environmental impact assessment process, a checklist is suitable for identifying impact, describing the affected environment and subsequently communicating the findings. It is also important to stress out that the management of the environment at the construction sites is being implemented based on the ISO14000 Environmental Management System framework. This probably explains why a checklist is the most common tool that suits inspection purposes. And as a cross check, fifteen (15) Construction Environmental Management Plan (CEMP) for major construction projects in the Malaysia and United Kingdom (UK) have been selected randomly either from the internet or hardcopy, and examining the use of checklists for their projects have been duly carried out. The list of selected Construction Environmental Management Plan (CEMP) can be found in Appendix 1. Thus, it is confirmed that the checklist is the most common tool that is used for inspection purposes. In addition, it is also noted that, typically, the checklist contains the following information:

1. Reference number
2. Location
3. Name of project owner/contractor
4. Name of inspector
5. Date and time of inspection
6. Weather condition

7. Environmental aspects and impacts of the project
8. Rating of compliance

In addition to checklists, the European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL)(1999) has listed other inspection tools which the inspector can/must use during the site visit. These include:

1. Writing material/laptop computer;
2. Technical drawings of the premises and the plant;
3. Process diagrams;
4. Reports and letters, etc. from previous inspections;
5. Notices sent to the factory;
6. Equipment to take samples of the soil, air-emissions, noise-emissions etc.;
7. Mobile phone where appropriate (although in some cases permission may be required to bring it onto the site);
8. Photo/video camera;
9. Personal protection equipment.

2.4.1.4. CHALLENGES AND LIMITATION OF AN INSPECTION

Obviously, a particular inspection should follow the inspection phase as in the Figure 2-4 while the inspectors have to put emphasis on the installation as highlighted in the Table 2-2. As for the dust control for instance, RWDI AIR Inc. (2014) in their best management practice plan had described that the inspectors should complete walkthrough inspection and interviews once they entered the construction site. This involves the observation on the following:

- a. The condition of exposed areas (i.e. working face, interim cover, stockpiles, unvegetated areas, etc.), construction areas and ancillary sources to ensure that excessive wind erosion or fugitive dust emissions do not occur. If wind erosion or fugitive dust emissions from these sources are noted, additional cover treatment and/or watering suppressants should be applied and noted in the log.
- b. Cleanliness of internal and external paved roads. This is to ensure the roads are clean at all the times especially under the adverse weather conditions where the wet sweeping is to be done at all the roads.

- c. Dust plumes from on-site vehicles. The visible plumes behind vehicles should not be greater than 1 vehicle length on unpaved and paved on-site roadways. Watering and/or sweeping of roadways should be ordered when this occurs and should continue until the condition abates.

The inspectors are also required to record and examine wind conditions from the on-site weather station as well as make a reference to the on-going ambient air quality monitoring of total suspended particulate matter. In the even where the real-time ambient air quality monitoring is applied on sites, the inspectors would refer to the actual real-time data in order to establish cause – effect relationships. Otherwise, the inspectors would only have the past monitoring data to refer, as the monitoring result for the day of inspection is expected to be obtained later due to a longer process e.g. sample collection, laboratory analysis, data handling, and etc. In addition to that, the inspectors are also required to review the maintenance records and the dust log which contain portioned sections for training, inspection, watering activities, road sweeping log, remediation activities, general notes and complaint logs. Figure 2-5 summarised the whole activities involved during the dust control programme together with the places where it was conducted and tools that were required.

Therefore, due to the activities involved and the methods on how each activity was carried out, the inspection possess significant challenges in the implementation. First and foremost, despite being acknowledged as the backbone of most enforcement programmes in the field of environmental management due to their ability to provide the most relevant and reliable information, inspections can also be very resource-intensive (International Network for Environmental Compliance and Enforcement (INECE), 2009). Traditionally, most of the inspection tools as listed in Section 2.4.1.3, especially the checklist, are mainly in the form of paper. As a consequence, the inspector has to carry all these paper-based documents to the site, whether for reference or for writing material, during the site inspection. Thus, the inspector has to record the data collected on site by using a paper-based checklist and relying on paper-based reports, plans, etc. as sources of information. Moreover, the inspector frequently takes photographs using a conventional camera to provide evidence to support his findings. However, it is important to note that these documents are difficult to carry in big quantities and offer very limited sources of information at a particular moment of time (Chen and Kamara, 2011). The limited information in the paperwork makes the

inspector is often unable to react to a rapidly changing context and fails to demonstrate the interrelationship between activities and their consequences in timely manner.

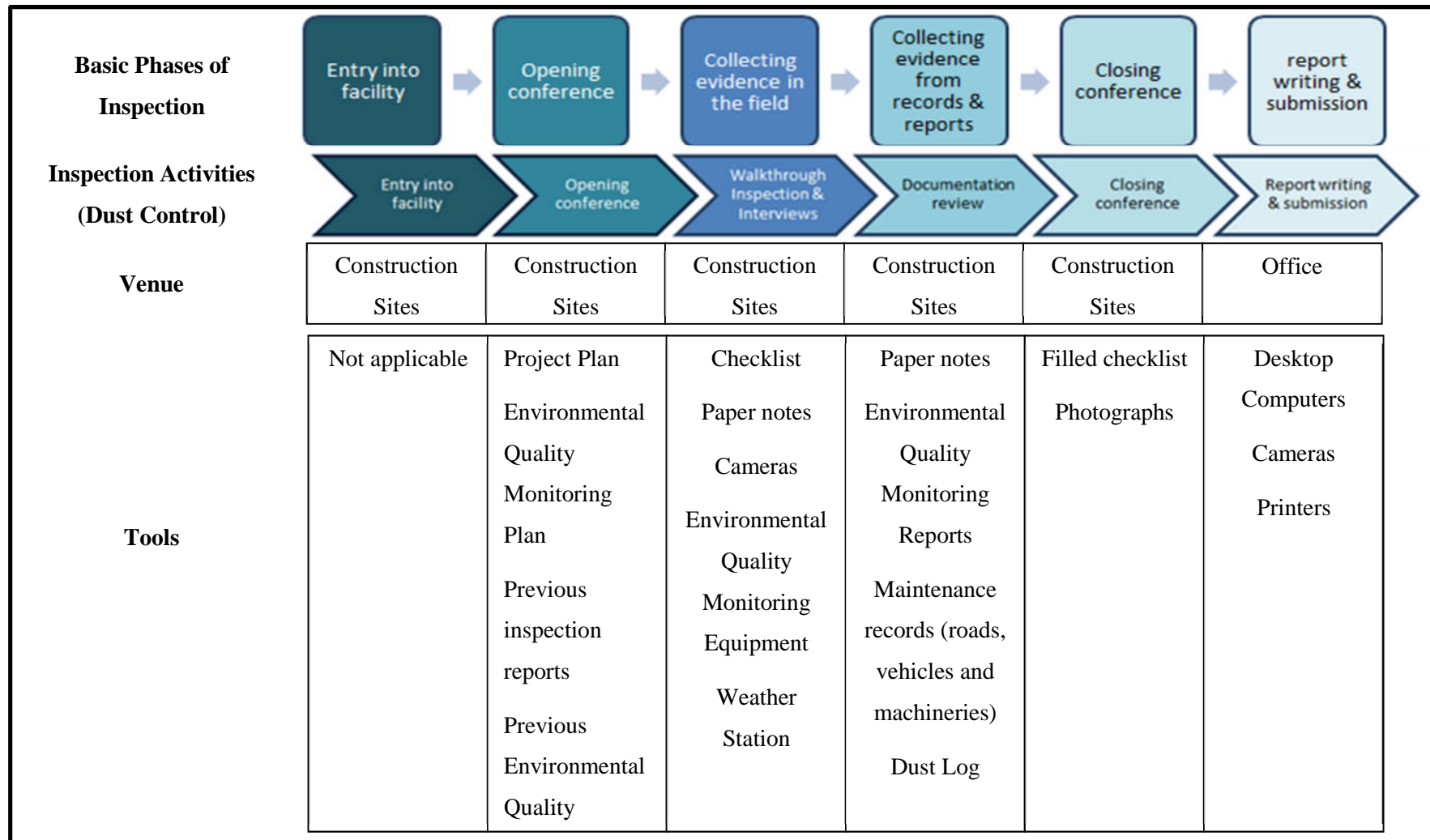


Figure 2-5 Inspection Activities for the Dust Control

Once an inspector has collected all the information, the checklist is usually sent back to the office where it is given a reference number. The photographs will be downloaded to the computers and manually sorted. In addition, for any inspection that involved traditional grab sampling, the sample will be analysed in-house or by sending it out to a laboratory. Then, as it takes some time for sampling analysis to occur, the observational report will be written up while waiting for the results of the sampling. The writing up of the report might be finished sooner than the sample analysis depending on the complexity of the environmental issues on the site. Therefore, in some cases, the observational report might be issued by the inspector without including the sampling results. The sampling results will then be sent out later as an addendum to the report.

The processes described above usually involve some type of filing method. Checklists and reports are usually placed into a filing cabinet to be stored ready for retrieval at a later date. However, the time spent in collecting, filing and distributing the paper forms in this manual process raises many concerns. Not only is the clerical expense of the process very high but also the organisation and review of the information commands an inordinate amount of time from a project manager, and most project managers have great time pressures. In response to such concerns, a first attempt to solve this problem is to transfer the information, once collected, to a computer database where it can be viewed, manipulated and distributed electronically.

Although this second method helps save vast amounts of time in terms of the processing and presentation of data, it does very little to eliminate the use of paper forms altogether. Specifically, this process still requires the double manipulation of data, once in the field and then the re-entry of the data in the office. This issue raises additional concerns as it increases the possibility of typographical errors causing inconsistencies in information as well as the loss of information in some instances.

In addition, physical surveillance has limitations in terms of describing the physical, chemical and biological characteristics of air, water, soil and other factors. And this is the reason why there is a need for environmental monitoring (measurement) in any EMS.

2.4.2. ENVIRONMENTAL QUALITY MONITORING (MEASUREMENT)

Monitoring can be defined as regular sampling for the acquisition of quantitative and representative information on the physical, chemical and biological characteristics of air, water, soil, wildlife and other factors over time and space (D. Prodanovic, 2007, Strobl and Robillard, 2008). With the aim of tracking system behaviour and its response to management (D. Prodanovic, 2007, Harrington and Canter, 1998), environmental monitoring could enhance the environmental management process due to its ability to provide the information on: (1) improvements in impacts prediction technologies; (2) reviewing mitigation measures; (3) providing alerts on unexpected or significant impacts; (4) documentation of project needs, and (5) more exhaustive descriptions of the affected environment (Harrington and Canter, 1998).

Traditionally, environmental quality monitoring includes six (6) main activities in sequence as shown in Figure 2-6. For any environmental quality monitoring, monitoring stations will be located, and decisions on the variables and sampling frequencies will be made, at the commencement stage. A sampling exercise will then be executed once these issues have been decided. Sampling is undertaken by using monitoring equipment devices (typically electrical). This monitoring equipment will convert any measured nonelectrical quantity, such as water level, into an electrical quantity that can be stored and processed for the measurement of various parameters. In ordinary monitoring at a construction site, field information previously has been acquired by collecting data periodically through the collection of physical samples and/or the installation of a data logger at the sampling field while observation is supported by a checklist and a layout plan in hardcopy format. Subsequently, the physical samples will undergo laboratory analysis and/or the sampled data in the data logger will be uploaded into a computer system by using a diskette or any other temporary data storage devices before an analysis is carried out. The information derived from the analysis will then be disseminated through a hardcopy report presented to the respective parties.

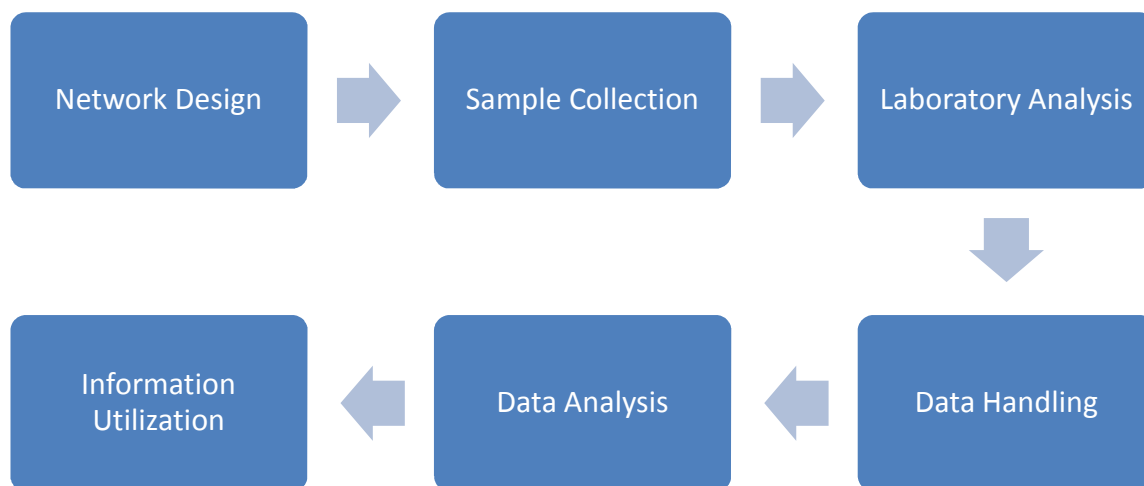


Figure 2-6 Main Activities of Environmental Quality Monitoring (EQM) (Sanders et al., 1983, cited in (Strobl and Robillard, 2008)

The environmental quality monitoring of the construction projects, however, only looks at the parameters which are relevant to the environmental aspects of the construction activities. In the context of Malaysia, environmental quality monitoring at any construction sites is commonly monitored fortnightly (Pembinaan Mitrajaya Sdn. Bhd., 2012, Harun, 2006, TSR Bina Sdn. Bhd., 2013). For a better understanding, Table 2-3 provides the applicable monitoring parameters (pollutant) for construction activities.

Table 2-3 Monitoring Parameters and Limits

Parameters	Permitted Limits	Type of Analysis
Noise		
A continuous A-weighted sound pressure level (dB(A))	Should not exceed 65dB(A) in the daytime	Measurement of the sound pressure level
	Should not exceed 55dB(A) in the night time	
Air		
Particulate Matter (PM ₁₀)	40 µg/m ³ for annual averaging period or 50 µg/m ³ averaging period of	Light scattering and photometric analyzer

Parameters	Permitted Limits	Type of Analysis
	24 hours.	
Nitrogen dioxide (NO ₂)	200 µg/m ³ for averaging period of 1 hour or 40 µg/m ³ for annual averaging period	Ultraviolet-Visible Spectroscopy (UV); Differential Optical Absorption Spectroscopy (DOAS); Infrared (IR); Fourier Transform Infrared (FTIR); Chemiluminescence; Electrochemical
Water		
Total Suspended Solids (TSS)	50mg/L	Filtration and gravimetry
pH	6-9	Electrochemical (pH meter)
Dissolved Oxygen (DO)	5-7mg/L	Iodometric Titration
Temperature	Normal +/- 2°C	Temperature meter

Source : The Institute of Environmental Management and Assessment (IEMA) (2005), Perbadanan Putrajaya (1998), Chambers (2005) and Artiola et al. (2004)

Although there are seven (7) parameters which are commonly being monitored fortnightly at construction sites in Malaysia, this research will only focus on the most risky environmental impacts on construction sites in Malaysia. Table 2-4 shows the result of the recent study by Zolfagharian et al. (2012) that ranked the top five (5) environmental impacts of construction processes based on the risk levels. Out of these environmental impacts, however, only ‘Noise Pollution’ and ‘Dust Generation by Construction Machinery’ can be measured by the environmental quality monitoring which is through the Noise Quality Monitoring (A continuous A-weighted sound pressure level) and Air Quality Monitoring (Particulate Matter) respectively. Whereas, for the others, the monitoring should be made through other type of approaches such as Process-based Analysis (Dixit et al., 2010), site inspection (Munoz et al., 2001) and etc.

Table 2-4 The Environmental Impacts Assessments of Construction Process
(Zolfagharian et al., 2012)

Environmental Impacts	FOC^a	SD^b (FOC)	SEV^c	SD (SEV)	IL^d	Priority
Transportation Resource	3.79	0.89	3.36	0.93	12.71	Priority 1
Noise Pollution	3.67	1.05	3.23	1.09	11.85	Priority 2
Dust Generation with Construction Machinery	3.46	1.2	3.31	1.03	11.45	Priority 3
Energy Consumption on Site	3.24	1.06	3.36	0.87	10.89	Priority 4
Site Hygiene Condition	3.25	1.14	3.31	1.03	10.75	Priority 5

^a FOC, Frequency of Occuring

^b SD., Standard Deviation

^c SEV, Severity of the impacts of on the environment or consequences

^d Impact Level

2.4.2.1. NOISE QUALITY MONITORING

Construction activities contribute significantly to noise pollution problems. According to Chen et al. (2000), noise impacts caused by construction activities mainly come from demolition activities and construction machinery such as pile drivers, cranes, rock drills, mixing machinery and other machinery mostly used for substructure works. Previous research carried out by Ballesteros et al. (2010) on the construction site of a housing block based on a concrete structure has proven that the excavation stage is the noisiest construction stage due to heavy machinery used in that stage which produces noise more constant than that registered in other stages; this is due to the characteristics of the engines and the excavation activities themselves.

Noise is defined as unwanted sound and carries the same characteristics as sound (Chambers, 2005, Hamoda, 2008, Ng, 2000). Thomson and Poynting (1906) describe sound as waves in the surrounding air which arise due to vibrating sources. As a reflection of waves at the sources, sound needs time to travel through various mediums. Therefore, sound may refracted along its travelling period when passing from one

medium to another in which its speed is different and sound exhibits interference if there is any in between the mediums (Thomson and Poynting, 1906, Chambers, 2005). The ear will recognise sound by its definite wave-length in one set. Sound can consist of multiple waves in different lengths which can be related to each other (Thomson and Poynting, 1906). However, in contrast, it can result in the ear not being able to pick out any one set of waves, and then it hears only noise.

The propagation of sound waves in a travelling medium creates quantifiable pressure changes that affect the density of that medium. The parameter that addresses these pressure changes is known as the Sound Pressure Level (SPL) which can be expressed using a dimensionless unit, the decibel (dB). Most noise monitoring programmes measure noise impact through its level in decibels. Recent research has shown that there are other important features of noise that can be important and which need to be taken into account such as duration of exposure, impulsivity, frequency and spectrum, incidence and distribution along the working day (The Institute of Environmental Management and Assessment (IEMA), 2005, Kinsler and Frey, 1962, Fernandez et al., 2009). The Institute of Environmental Management and Assessment (IEMA) has discussed these features and their measurement as shown in Table 2-5.

Table 2-5 Different characteristics of noise and their measurement

Feature	What to measure
Continuous noise at constant level.	A short sample is only needed to characterise it.
Continuous noise that fluctuates in level	Statistical sampling is needed (L_{10} , L_{90} ; or Total energy in representative measurement period, T, ($L_{eq,T}$).
Intermittent noise	Total energy of an individual event (SEL), or Average energy of a number of events over period, T, ($L_{eq,T}$), or Average maximum level of the events (L_{max}), or How the maximum compares with the noise between the events (L_{max} (of the events) compared with L_{eq} or L_{90} (no

Feature	What to measure
	events)), or The number of events in a period.
Frequency content of noise	Linear or A-weighting. (C-weighting may be useful if the noise has a strong low frequency component); Octave or 1/3 rd octave frequency bands.
Time of day noise occurs	Time of day is of interest (although it is sometimes possible to extrapolate results from one time of day to another).

However, it is important to note that the decision on what to measure depends on the purpose of the measurements. For noise quality monitoring on construction sites, the noise impact is still being measured through the measurement of the sound pressure level on people who are expected to be exposed to environmental noise within a given noise duration. The measurement unit for this can be expressed using a continuous A-weighted sound pressure level (dB(A)). The dB(A) actually is the unit of noise measurement that expresses loudness in terms of decibels (dB) based on the weighting factor of humans' sensitivity to sound (A) (URS Corporation, 2008). This measurement, however, is incomplete if without the time factor. Table 2-6 shows a few terminologies and abbreviations which are being used in order to factor-in the time consideration.

Table 2-6 Terminologies and Abbreviations for Noise Measurement Units

Abbreviations	Terminologies
LA1, LA5, LA10, LA50, LA90, LA99	A-weighted noise level exceeded for 1, 5, 10, 50, 90 or 99% of the measured time.
LAeq	Equivalent continuous A-weighted sound level over a given period of time.
LAmax	Equivalent maximum continuous A-weighted sound level over a given period of time.
LAmin	Equivalent minimum continuous A-weighted sound level over a given period of time.

Source: The Institute of Environmental Management and Assessment (IEMA)

The British Standards Institute (BSI) has categorised noise into three categories, namely ambient noise, specific noise and initial noise (British Standards Institution (BSI), 2003). Ambient noise comprises sound from many sources, either from near or far sources, in a given situation and time. For example, ambient noise during demolition work at a certain time period may consist of the noise produced by hacking activities, drilling machines and human activities. Thus, ambient noise monitoring during that time will provide the noise level at a stipulated time period in general without any identification of the specific noise contributors. In comparison, a specific noise is produced by a specific source and can be specifically identified by acoustical means. This means that ambient noise is created by the combination of many specific noises whereas initial noise is the ambient noise prevailing in an area before any modification of the existing situation.

The ambient noise monitoring process at a construction site is something similar to the gathering and processing of quantitative and qualitative data in order to enable the project proponent to assess the noise impact associated with the development (URS Corporation, 2008). The end results from this process represent the sound pressure level in the forms of “Long-term Average Sound Level (LAeq)” and “Long-term Average Rating Level (LAeq,T)” at a specified monitoring location. The sound level meter will record the equivalent continuous A-weighted sound pressure levels for each reference

time interval; the rating levels for each reference time interval; the long-term average sound level and the long-term average rating level. The monitoring process has to be carried out in such a way that conforms to standards and procedures in order to ensure efficiency and accuracy.

The purpose of ambient noise monitoring is to represent and characterise the noise for a particular construction site. It has to be undertaken at outdoor locations where the monitoring station basically will be positioned at the perimeter of the construction site but still within the approved development plot as per planning permission approval. The location and the number of the monitoring stations may vary between construction sites and it depends upon the required spatial resolution for the environment under consideration (British Standards Institute (BSI), 1991). The monitoring station, however, has to be positioned at least 3-5m away from any reflecting structures and its microphone has to be at least 1.2-1.5m above the ground. As has been mentioned in an earlier section, noise may refracted along its travelling period and may exhibit interference between its original source and the monitoring station (Thomson and Poynting, 1906, Chambers, 2005). For this reason, all such refractions have to be avoided or otherwise corrections need be made. For instance, if measurements are made 1 to 2m in front of the facade of a building and the noise spectrum is of broad-band type with no dominating narrow band or pure tone, an approximation of the incident sound pressure level may be obtained by subtracting 3dB from the measured value. Generally, the monitoring location must be selected based on the following criteria. It must:

- a. Be placed at the site boundary or at locations that are close to the major pollutant sources;
- b. Be close to the identified sensitive receptors, and
- c. Take into account the prevailing meteorological conditions.

Since ambient noise comprises sound from many sources, the monitoring team personnel have to record and describe the sounds in terms of their characteristics, connotation, sources and receivers. They would also have to report on the geographical description of the area under consideration. This includes the topographical features, local shielding effects, land use (existing and planned), etc. In addition, conditions such as those given by a humidity indicator in relation to rain, drizzle, heavy rain, dry, wet; the direction and speed of the wind, etc. are other aspects that need to be considered and

have to be put together on the record during the monitoring period. This is because ambient noise monitoring for construction activities is totally different when compared to indoor monitoring as construction sites are exposed to meteorological conditions. These meteorological conditions can affect noise and the sound pressure level results may not be as accurate as expected.

Noise monitoring instruments used on construction sites are similar to noise monitoring instruments used in other applications. The basic monitoring instrument includes a sound level meter, a microphone and an acoustic calibrator. All these are currently available in the market. Cirrus Research Plc, for example, offers a commercial noise measurement kit specifically for noise measurement at construction sites which includes:

- a. An optimum green sound level meter (version 0, A or B)
- b. An acoustic calibrator
- c. A 10 meter microphone cable
- d. A battery pack with intelligent power management
- e. A charger for the battery pack
- f. A weather-proof outdoor microphone
- g. An optional tripod can also be supplied

As this kit is applicable for monitoring outdoor noise where an electrical supply can be an issue, a battery pack is used in order to ensure a continuous power supply for the equipment. This standalone power supply will ensure the equipment runs for 24 hours in a 7 days' operation. Outdoor noise monitoring is exposed to meteorological conditions. Thus, a weatherproof outdoor microphone will ensure there is no interruption to the recording of noise in any weather condition and that the quality is assured. The tripod is supplied so that the microphone can be positioned at least 1.2-1.5m above the ground. This is a sample of a noise monitoring instrument that is offered by one commercial company and there are many other companies, namely Casella Measurement (Casella, 2015), Pulsar Instruments Plc (Pulsar Instruments plc, 2015), Magus Monitoring (Magus Monitoring, 2015)etc., which also offer noise monitoring equipment within their range.

2.4.2.2. AIR QUALITY MONITORING

Air pollution is the appearance of air contaminants in the atmosphere which can create a harmful environment for human health and welfare, animal or plant life, or for property (Wang and Chang, 2005). For example, the exposure of humans to a high content of Lead (Pb) in the air can affect health and may cause chronic toxicity, impaired blood formation and create negative effects on infant development. A high content of Sulphur Dioxide (SO₂) in the air is the main cause of the formation of sulphuric acid and acid rain which can damage plants and create odour. These are examples of the negative effects of air pollution on human health and the environment.

There is a number of air quality impacts associated with construction activities, specifically emissions generated by construction equipment and vehicles on-site; dust generated during demolition, earth moving and construction works; emissions from road traffic during construction and as a result of the operation of the proposed development, and atmospheric releases from any stationary combustion plant (heating equipment and power plant) associated with the completed development.

Realising the negative impacts of air pollution on human health and the environment, the Government of Malaysia has produced Malaysian Air Guidelines. The guidelines are the principal air quality legislation within the Malaysia and provide the regulated documents containing the standards, objectives and measures for improving ambient air quality and keeping policies under review. It has spelt out the assessment criteria for seven (7) types of pollutants which need to be measured as shown in Table 2-7.

Table 2-7 Malaysian Air Quality Guidelines Objectives (g/m³)

Pollutant	Objective	Averaging Period
Nitrogen dioxide (NO ₂)	320	1 hour
Particulate matter (PM ₁₀)	50	Annual
	150	24 hour
Carbon monoxide (CO)	35	1 hour
	10	8-hour
Ozone	200	1 hour
	120	8-hour
Particles TSP	90	Annual
	260	24 hour
Lead	1.5	3 months

Sulphur dioxide (SO ₂)	500	10 minute
	350	1 hour
	105	24 hours

Source : Perbadanan Putrajaya (1998)

A detailed assessment is, however, required before deciding which criteria are going to be measured in a particular air quality monitoring programme. This is because not all these pollutants are going to be generated within one type of project. For a construction project in Malaysia, for example, Particulate Matter (PM₁₀) is the most significance air pollutant from the various activities on construction sites (Zolfagharian et al., 2012).

Particulate Matter (PM₁₀) refers to fine particles dispersed in the atmosphere (URS Corporation, 2008; Wang and Chang, 2005). It is composed of a wide range of materials arising from a variety of sources, including, for example, combustion (mainly road traffic) and the suspension in the air of soils and dusts from construction work. Particles are measured in a number of different size fractions according to their mean aerodynamic diameter. PM₁₀ 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 heart and lung diseases.

In a manual traditional method, PM₁₀ is monitored using standard high volume samples and the concentration is determined using the standard specification APHA 111.1-01-70T (Perbadanan Putrajaya, 1998). Air samples are collected in sample bags made of inert material such as Teflon and are then sent to a laboratory for analysis. PM₁₀ analysis involves inertial separation using multiple chambers to divide particulates into one or more size classes with a 10-µm-diameter limit (Janick F. Artiola et al., 2004). Each particle size is captured on a separate filter paper which is subsequently weighed to estimate the amount of particulates retained per unit volume of air.

Similar to the requirements for noise monitoring, a baseline air monitoring survey prior to the submitting the application for planning permission and a continuous programme of on-site ambient air monitoring throughout the construction period is a compliance requirement for a certain type of project. In order to ensure that any significant deterioration in air quality is readily detected, air quality monitoring is required to be carried out at designated monitoring locations. The method to determine the air quality monitoring locations is based on similar criteria as for the noise monitoring, such as:

- a. Being at the site boundary or locations that are close to the major pollutant sources;
- b. Being close to the identified sensitive receptors, and
- c. Taking into account the prevailing meteorological conditions.

Therefore, usually the air and noise quality monitoring stations will be placed at the same locations.

2.4.3. TECHNOLOGICAL BASED SURVEILLANCE

Technological based surveillance involves acoustic surveillance (audio, infra/ultrasound and sonar), electromagnetic surveillance (radio, radar and infrared, visual, aerial ultraviolet and X-Rays), chemical and biological surveillance (chemical and biological, biometrics, animals and genetics), magnetic sensing, cryptologic surveillance and computerized surveillance (Petersen, 2012). However, it is important to note that these technological devices can only suit certain purposes of surveillance. The details of each technology are elaborated as in Table 2-8.

Table 2-8 Surveillance Technologies (Petersen, 2012)

Nos.	Surveillance Technologies	Description
1.	Acoustic Surveillance	
a.	Audio	Audio Surveillance is using a technology that dealing with sounds within human hearing ranges. It is intended to improve our sense of hearing, as well as to enhance other forms of stimuli and convert them to our hearing range. Audio surveillance happens over both wired and wireless systems. The contexts wherein audio surveillance are generally used include sound monitoring in the field, home, or workplace; eavesdropping; wiretapping; and mobile listening/recording .

Nos.	Surveillance Technologies	Description
b.	Infra/Ultrasound	<p>Infrasound is a sound at frequencies below human hearing while ultrasound, sounds above human hearing. Infra/ultrasounds have a lot of advantages as surveillance tools because they can communicate or signal across distances without drawing attention. In addition, sound signaling is usually cost-effective as it is more convenient to generate certain sound frequencies and listening devices. Usually, this type of technology is frequently being utilized for monitoring of large natural events and explosions.</p>
c.	Sonar	<p>Sonar detection was in the past a manual process where an operator would listen to the pings through earphones. Nowadays, the pinging sound of a sonar system is commonly broadcast in movies depicting submarines and other underwater vehicles. This audible reference symbolizes the infinite sound surveillance technologies utilized to search for vessels or structures underwater. Some sonar sounds are within human hearing ranges but many are not. Common application of this technology comprises of surface or underwater navigation, detection of other bodies underwater, object and terrain mapping, underwater communications, and robotics ranging applications (both under and above water).</p>

Nos.	Surveillance Technologies	Description
2.	Electromagnetic Surveillance	
a.	Radio	<p>Radio is amongst the most important surveillance technologies ever developed. Radio waves work over a range of frequencies that could be used at low or high intensities. They are able to pass through many objects, including biological systems, walls, windows, and fences. Due to the fact that radio signals can be sent on numerous frequencies simultaneously without necessarily interfering with each other, radio waves can be used in several different applications, including television and radio broadcasting, phone and computer communications, radar sensing, imaging, tracking tags and wireless networks.</p>
b.	Radar	<p>Radar is an acronym variously described as radio direction and ranging and radio detection and ranging. It is a remote-sensing technology for detecting and interpreting radio signals, usually in the microwave frequencies. Radar systems can be passive or active. In active radar, radio signals are emitted toward an object or structure with the intent of intercepting and interpreting the reflected signals (the incident electromagnetic energy). The contexts in which radar surveillance are most commonly used include military targeting, tracking and defense, and civilian monitoring of vassels, hazards, threats, environmental changes and weather system.</p>

Nos.	Surveillance Technologies	Description
c.	Infrared	<p>The rule of thumb is that, if something emits heat, or contrasts with the ambient temperature, it is a good candidate for thermal infrared detection. Common infrared targets include people (customers, intruders), wildlife (game, injured livestock, research animals, insects, birds that migrate at night), astronomical bodies, electrical faults, fires, drug-growing operations, underground or building piping systems (especially heat ducts or hot water pipes), circuit boards, buildings (roofs, walls), and fires (arson, house fires, forest fires).</p>
d.	Visual	<p>Visual surveillance devices range in size from many tons to pinhole video cameras so small they can be hidden in a tie clip. Its enable us to see farther or more clearly even in low-light conditions, monitor activities in difficult areas, and protective suits and vehicles enable us to move about and observe in hazardous areas. These also enable us to store and review visual images. Local and federal law enforcement agents (traffic control, stake-outs, patrols, prison management), federal military defense agents (aerial, orbital, and marine surveillance), private citizens and aspiring entrepreneurs (home security, nanny cams, voyeur products, prospectors), environmental protection groups seeking to protect the ecosystem and its inhabitants, public and private businesses (business security, employee monitoring, industrial safety, private detectives, salvage</p>

Nos.	Surveillance Technologies	Description
		companies, insurance adjusters), search and rescue teams (military zones, natural disaster zones), and paparazzi and the media in general (investigative reporting, news and weather reporting, celebrity stalking) are the common users and applications of this kind of technology.
e.	Aerial	Aerial surveillance is used in many government and commercial activities, including national defense, local law enforcement, disaster assessment and relief, community planning, building permit issuance and compliance monitoring, resource exploration, wildlife monitoring, property tax assessment, border patrol, search and rescue, weather reporting, property value and damage assessment, crop yield assessment, forestry, firefighting, and many more.
f.	Ultraviolet	Ultraviolet wavelengths are shorter than visible lightwaves which, in turn, are shorter than infrared. Ultraviolet-reflecting substances are useful for many types of marking and identification, including crowd control, valuables marking, fingerprint detection, mineral identification, and stamp and currency security encoding as well as forensic weathering tests and astronomical research.
g.	X-rays	Sensing devices that operate in the optical frequencies are called photodetectors and some broadband devices that detect radiation in the visible spectrum also detect infrared and

Nos.	Surveillance Technologies	Description
		ultraviolet frequencies. Many organizations use X-ray machines for medicine and preventive health care, cargo and luggage inspection, archaeological, artifact, and art inspection, industrial testing, inspection, and quality control, military and astronomy.
3.	Chemical & Biological Surveillance	
a.	Chemical & Biological	Chemical and biological surveillance are technical fields as it is involving a laboratory work on a microscopic scale, sometimes in sterile or carefully monitored environments. Chemicals are useful for detecting, marking, tracking, and influencing chemical reactions or behavior or sometimes they are even used as decoys. This includes the detection and analysis of evidence at a crime scene, drug detection, vapors at an industrial accident, safety and hazards monitoring, search and rescue, firefighting, arson investigation, or the presence of chemical weapons in hostile territory or at border crossings.
b.	Biometrics	Biometric surveillance is the detection, identification, and tracking of individuals based upon unique physical characteristics or attributes such as proportions, size, color, fingerprints, iris patterns, or voice patterns. Thus, biometrics are primarily used in law enforcement especially for criminal and suspect identification (fingerprints and mug shots), in the workplace, and in retail (entry access, and transaction verification) and

Nos.	Surveillance Technologies	Description
		financial centers (they are applied in more specialized laboratory research as well, as in anthropology, kinesthetics, and medicine).
c.	Animals	The use of animals in surveillance and search-and-rescue operations can be highly effective. Animals can be used as ‘passive’ sensing organisms, as well. Their natural calls can be effective surveillance “alarms”. As examples, Sea lions can perform a variety of tasks, from finding stowaways, criminals, and lost children to seeking out mines and shipwrecks. Similarly, natural animal behaviors, such as the scattering of rabbits or deer, might indicate the presence of a large predator or an approaching storm or fire. Thus, this kind of approach is being used for search and rescue; explosives and firearms sniffing; narcotics, pest, and agricultural sniffing; pipeline management and hazardous materials detection; and others.
d.	Genetics	DNA testing is a generic technology that can be applied in many aspects of life. It is used in law enforcement, poaching and wildlife conservation management, social services (especially child-support disputes and genetic counseling), crop evaluation, seed management, dog and livestock breeding, drug control, and many other areas in which information about the lineage, composition, or the whereabouts of an animal or plant is desired.

Nos.	Surveillance Technologies	Description
4.	Miscellaneous Surveillance	
a.	Magnetic	<p>Magnetic surveillance is a versatile technology that can be used to detect both living and nonliving targets. When electricity is applied to substances with good conductivity, such as copper or iron, it is possible to turn them into electromagnets. This kind of technology is commonly being used for Archaeology, Detection of Land Mines and Bomblets, Electronic Article Security (EAS) Surveillance</p> <p>Detection of Submarines, Shock Wave Detection and Research.</p>
b.	Cryptologic	<p>Cryptology is the study of the discovery and analysis of coded and hidden information. Cryptologic surveillance involves seeking, analyzing, and decoding coded messages. The decoding process is more specifically known as the field of cryptanalysis. Cryptologic surveillance is a subset of cryptology, the part of the process that occurs after the devising of codes and the encoding of messages. Application of this technology comprises of the deciphering or discovery of a hidden or coded message intended for someone else.</p>
c.	Computers	<p>Computers are changing the surveillance industry in dramatic ways. There are three aspects of computers that make them particularly suitable for surveillance tasks: 1) microelectronic components can be used to design, test, and automate surveillance devices, 2) they can</p>

Nos.	Surveillance Technologies	Description
		quickly process enormous quantities of data, and 3) they can be interconnected to share information. The three main areas of computer surveillance that have been introduced have been surveillance of information on the Internet, computer profiling, and workplace surveillance.

Obviously, in the context of environmental management within the construction industry, technological based surveillance is being used for environmental monitoring (measurement) (Jang et al., 2008, Kwon et al., 2006), waste management, soil studies (Cardell-Oliver et al., 2004), early-warning systems and the management of materials (Lu et al., 2011, Razavi and Haas, 2011). As there are many disadvantages to be found within traditional environmental monitoring (measurement), technological based surveillance has become an alternative. The advancement in sensor technology has added value to environmental monitoring by providing the ability to quantify and represent information on the physical, chemical and biological characteristics of a certain monitoring parameters in a new way.

As has been discussed in the earlier sections, it can be concluded that traditional laboratory analysis is sophisticated and sensitive, but it is often inconvenient for field use because of the need to transport samples to a laboratory and then wait for the determination of results (Damian et al., 2007). The travelling time can be long and there is always the possibility of late arrival at the laboratory and that it is already closed (Mohamad and Aripin, 2006). Moreover, the laboratory processes themselves can prove to be time consuming. For instance, water quality monitoring for the parameters of Total Suspended Solid (TSS) and Dissolved Oxygen (DO) can normally take 5-7 working days to complete. In addition, previous research has agreed that, although traditional environmental quality monitoring is robust, it is certainly challenging, labour-intensive, susceptible to georeferencing errors and can be exposed to deficiencies and discrepancies (Vivoni and Camilli, 2003, Kim et al., 2008).

The need for factual information and increased productivity in the environmental monitoring field has been met by the latest innovations in mobile information

technology which are able to be integrated with other devices to allow for real-time data acquisition and warning-alert systems. Martinez et al. (2004) suggest that the development of environmental monitoring applications needs to leverage the technology of Wireless Sensor Networks (WSN) which can utilise sensors, communication and computer technologies together with knowledge about the environment. As the focus of this research is to improve environmental checking and corrective action through environmental surveillance and particularly by communicating environmental information, this section will discuss technological based surveillance via the deployment of WSN for the environmental monitoring (measurement) of air and noise quality.

The development of a WSN is to assist in the detection, processing and transmitting of the object monitoring information within the network's coverage areas. The growth of WSN was motivated by military applications in the 1980s when the Defense Advanced Research Projects Agency (DARPA) acted as a pioneer in the development of research on WSN (Qinghua Wang and Ilanko Balasingham, 2010, Chong and Kumar, 2003). At that time, the area of interest extended from information collection generally to enemy tracking, battlefield surveillance and target classification (Arampatzis et al., 2005) but today such networks are widely used for the purpose of monitoring and tracking. Monitoring applications include indoor or outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, and seismic and structural monitoring (Flammini et al., 2009, Arampatzis et al., 2005, Mittal and Bhatia, 2010). Tracking applications include tracking objects, animals, humans and vehicles (Zhang and Zhang, 2012). Figure 2-7 depicts a typical WSN arrangement.

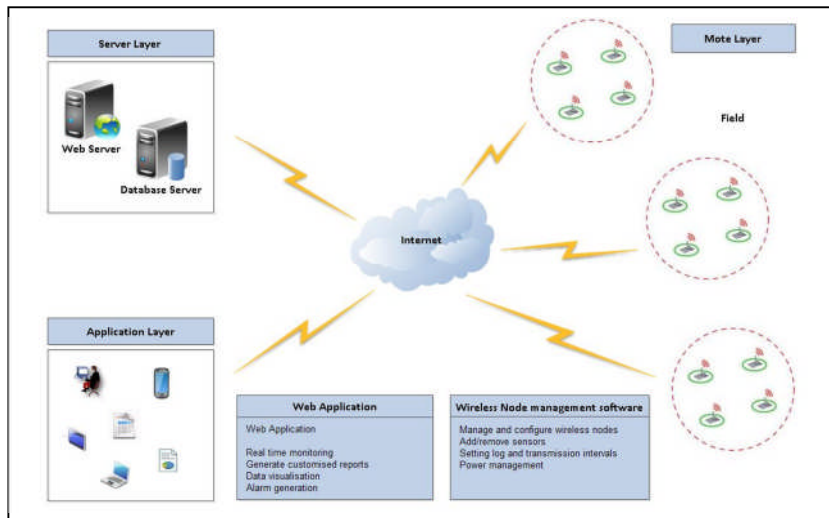


Figure 2-7 A typical WSN arrangement (Qinghua Wang and Ilanko Balasingham, 2010)

Such a network contains a large number of static or mobile sensor nodes and a designated sink point (gateway). Sensor nodes are scattered in a special domain called a sensor field (Akyildiz et al., 2002). Each of the distributed sensor nodes typically has the capability to collect data, analyse them, and route them to a (designated) sink point (Kazem Sohraby et al., 2007, Akyildiz et al., 2002). The sink point may then communicate with the user via the Internet.

The sensor nodes are small but have powerful devices that detect or sense a signal or physical condition and which later perform simple computations to convert the sensed data into an electrical quantity that can be stored and processed, or which can directly respond to a physical parameter for the purpose of measurement of a physical quantity or for information transfer (Barrenetxea et al., 2008a). Generally, the each of the sensor node contains the components as of the Figure 2-8.

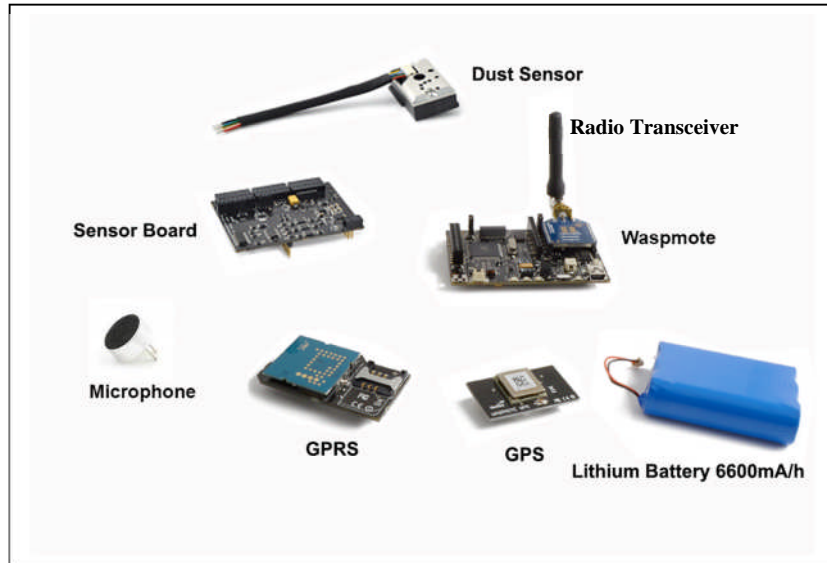


Figure 2-8 Components of Sensor Nodes

As in the Figure 2-8, the usual hardware components of a sensor node include a radio transceiver, an embedded processor, internal and external memories, a power source and one or more sensors.

i. Radio transceiver

Sensor nodes within the network need to be connected each other to enable them to communicate in order to transmit, receive and process the sensed information. Traditionally, cables are required to inter-connect devices within the network. This approach, however, although robust, leads to high installation and maintenance costs, e.g. due to low scalability and the high failure rate of connectors (Flammini et al., 2009). Moreover, due to the length of the cable, the system will have a limitation in terms of the spatial coverage of the system (Yang et al., 2008). Additionally, the installation of cable requires at least 50% of the total system's cost and 75% of the total testing time for large structures (Wang et al., 2005).

Because of these reasons, wireless technologies have proved enormously successful in the consumer goods' industry in the last few years. In addition, the adoption of wireless solutions at the sensor level offers other advantages: ease-of-installation; reduction of system disturbance; continuous, high-resolution, ubiquitous sensing; support for mobility; redundancy and compactness (Flammini et al., 2009, Taneja, 2007).

The wireless technologies for sensor nodes rely on the transceiver. There are various choices for wireless transmission media include Radio Frequency (RF), Laser and Infrared and, out of these three, RF based communication is the most common medium and fits most WSN applications. Table 2-9 shows the different types of wireless connectivity options that utilise the Radio Frequency (RF) of sensor nodes.

For an RF based sensor, the radio transmits messages at a distance of 25-30 meters (m) indoors and up to 7 kilometres (Km) outdoors on the 2.4 GHz band or on other frequencies which comply with their specific protocol. In addition, the radio would also provide extensive hardware support for packet handling, data buffering, burst transmissions, data encryption, data authentication, clear channel assessment, link quality indication, packet timing information, and mesh networks (Jang et al., 2008). It is important to note that each of the components within a WSN must use the same protocol to enable them to communicate to each other.

In addition, the user has an option to add sensor nodes with GSM-GPRS and 3G+GPRS. With these options, the sensor nodes would be able to make/receive calls, make 'x' tone missed calls, send/receive SMS etc. These options also create opportunities for the development of warning-alert systems as the sensor nodes would send a notification via SMS or a missed call to the users in any event of environmental non-compliance.

Table 2-9 Wireless Connectivity Options (Libelium Comunicaciones Distribuidas S.L, 2013a)

Communication radio	Frequency	Use Zone	Protocol	Distance
802.15.4	2.4GHz	World wide	802.15.4	100m- 500m
802.15.4-PRO				360m- 7Km
ZigBEE			ZigBEE- PRO	100m- 500m
ZigBEE-PRO				360m- 7Km
WIFI			802.11b/g	100- 300m
Bluetooth			Bluetooth 2.1 + EDR. Class 2	30-100m
GSM-GPRS	850MHz, 900Mhz, 1800MHz and 100MHz		GSM- GPRS	-Km- Typical Carrier Coverage
3G+GPRS	Tri-Band UMTS 2100/1900/900MHz Quad-Band GSM/EDGE 850/900/1800/1900MHz		GSM- GPRS-3G	-Km- Typical Carrier Coverage

ii. Embedded processor

In a WSN, each sensor node is equipped with an embedded processor to enable it to independently perform some processing and sensing tasks and control the functionality of other hardware components. There are many choices as to the

embedded processor such as Microcontroller, Digital Signal Processor (DSP), Field Programmable Gate Array (FPGA) and Application Specific Integrated Circuit (ASIC). However, due to its flexibility to connect to other devices and its cheap price, the Microcontroller has been the most used embedded processor for sensor nodes (Qinghua Wang and Ilangko Balasingham, 2010).

iii. Memory

Generally, the sensor node is equipped with an in-chip flash memory and the RAM of a microcontroller or an external flash memory. Two categories of memory based on the purpose of storage are: program memory used for programming the device and user memory used for storing application related or personal data.

iv. Power source

Batteries are the main source of power supply for sensor nodes. Most of the sensor nodes run on batteries to provide data communication, sensing and data processing. Schmid et al. (2005) carried out an analysis on the lifetime of 2 AA batteries within sensor nodes and they indicate that the average mote lifetime was 61 days at an average power consumption of 13.1 mV/day and with a maximum data rate of 4.64 packets/sec. This shows that there is a continuous need for batteries' replacement at certain intervals. This might create obstacles for the application of WSN in remote areas but should not prove a problem in accessible areas like city regions. Because of this limitation, minimising energy consumption is always a key concern during WSN operations (Wang et al., 2005). To attempt to remove the energy constraint, some research such as Kansal and Srivastava (2003), Morais et al.(2008) and others were working on energy-harvesting techniques to convert ambient energy (e.g. solar, wind) to electrical energy or photovoltaic charging has been conducted.

v. Sensors

The primary role of the monitoring equipment is to convert some measured non-electrical quantity, such as water level, into an electrical quantity that can be stored and processed. This conversion is undertaken within the element called a

transducer, a device that converts one type of energy into another, or responds to a physical parameter (Labor Law Talk, 2005) for the purpose of measurement of a physical quantity or for information transfer (ANST, 2000). Since the 1970s, the term sensor has been used widely instead of transducer. The sensor is a device that detects or senses a signal or physical condition.

A sensor node has one or several types of tiny built-in sensors that are connected to the node. This hardware device (sensor) is designed to produce a continuous measurable response signal (analog) to a change in a physical condition such as temperature, pressure and humidity while consuming extremely low energy (Qinghua Wang and Ilangko Balasingham, 2010).

For the measurement of PM_{10} and Sound Pressure Levels (SPL), it is common to use the Sharp dust sensor “GP2Y1010AU0F” and the Noise Sensor “Microphone WM-61A” as the sensors attached to the sensor nodes.

vi. Global Positioning System (GPS)

The Global Positioning System (GPS) is a system that uses a network of 24 satellites to triangulate a receiver’s position and provide latitude and longitude coordinates. The only downside with GPS technology is that it is useless indoors (Fathi et al., 2009). This is because the satellite signals that make it work are not all that strong and coverage can be spotty in cities with tall buildings. Therefore, to overcome this obstacle, A-GPS seems to be the solution. Integrated GPS can be Assisted GPS (AGPS) which offers a better performance than stand-alone GPS because of superior accuracy, quicker time-to-first-fix, and heightened sensitivity which leads to a better performance in challenging or blocked environments. This can be undertaken by adding the module of 3G+GPS into the sensor nodes.

Wireless Sensor Network architecture is not only about the sensor nodes. All the information coming from all the sensor nodes’ interfaces (ZigBee, Bluetooth, 3G/GPRS, Wifi and from the GPS module) can be stored in the Local File System and Local Data Base within the sink node (gateway) or even exported to an external Data Base connected to the Internet. Some of the sink nodes nowadays are complete Linux stations which offer different services, programming environments and storage systems.

This allows a user to control all the interfaces and system options in a secure, easy and quick way via a web interface Manager System. By default, the Linux station is installed with PHP web programming language and Mysql as a database system, and in terms of data storage, the Operating System and the Manager System of the sink node takes ~2.5GB (Libelium Comunicaciones Distribuidas S.L, 2015). Therefore, the space which can be used to store the data captured and used by the applications loaded by the user is of a minimum of 5.5GB and a maximum of 29.5GB. This secure and easy way of controlling, with the web interface Manager System and big data storage options, definitely offers huge opportunities for the sensors' integration with the Web. Thus, it allows for environmental data manipulation and presentation so that it can be used for other purposes on the Web such as accessing real-time news on the Web or becoming a part of an Environmental Management Information System (EMIS).

2.4.3.1. RELATED WORKS

One of the advantages of WSN is that sensor nodes can periodically sample and relay their sensor readings to a gateway connected to the Internet, allowing researchers around the world to access real-time environmental data (Zúniga and Krishnamachari, 2003, Ghobakhlou et al., 2011). Santini et al. (2008) for instance, have implemented the Ennowa (Environmental Noise Watcher) application. It has proved a prototype for the collection and logging of indoor and outdoor noise pollution data based on the Tmote invent prototyping platform for wireless sensor networks. The centrally collected noise samples can be stored in a database and then can be further processed and visualised on common map-based web-interfaces like Google Maps.

The urban air environmental monitoring system which has been proposed by Xianfeng et al. (2010) was also leveraged on the sensor network. By using PICNIC network cards and combo sensor kits for the measurement of temperature, humidity, carbon dioxide and oxygen, open source geospatial platforms are deployed, including the database system (PostgreSQL/PostGIS), the mapping system (Mapserver and Openlayers) and the web platform (Apache). Python is used as a glue language to integrate all the open system together.

A low-cost mobile urban pollution monitoring system for use in public transport vehicles, or in school and college buses, has been introduced in India. Abraham and

Pandian (2013) have developed a system based on the use of open source microcontrollers and off-the-shelf air quality sensors to capture pollution data, and on web technologies for the display and storage of the acquired pollution data on the Internet. The data can be displayed on pollution maps and environmental geographic information systems (GIS) with the intention of raising environmental awareness among citizens and of assisting public officials in environmental management in effective pollution control.

Additionally, there are also proven commercialised sensors and systems available in the market. Brüel & Kjær UK Ltd. has developed an online noise monitoring system which allows the users remote control access to the instrument via a mobile phone, PDA, iPhone or a PC with Internet browser capability (Brüel & Kjær UK Ltd, 2014). Brüel & Kjær's 2250, 2250 Light and 2270 meters are simply required to be active on a WLAN connection or are available on the Internet via a 3G, GPRS, EDGE or GPRS router connection. The user enters the unique IP address - or address label - of the instrument into the Internet address field on the browser to access the instrument via a mimic keyboard and touch screen display. By using a web services platform, they have managed to resolve the common problems in integrating existing applications (e.g. PDA, Palm, Pocket PC, Tablet PC) that come with different interfaces, programming languages and out-of-sync information. With this advantage, their online system enables users to monitor and manage a noise measurement setup and data in real-time.

The Smart Santander Project has been developed by several companies and institutions including Telefonica I+D and the University of Cantabria (Bielsa, 2013). It aims at designing, deploying and validating of the Smart City Concept in Santander and its environment is a platform composed of sensors, actuators, cameras and screens to offer useful information to citizens (Bielsa, 2013). Within it are 1125 units of sensor nodes which are made up of a combination of "Gases" and "Smart Cities" sensor boards plus 5 sensors which have been deployed to monitor different parameters such as noise, temperature, luminosity, CO and free parking slots. These sensor nodes are produced by Libelium, a company based in Zaragoza, Spain.

The EkoBus Project, which is funded by the European Union through its Future Internet Research and Experimentation (FIRE) programme, also uses the sensor nodes produced by Libelium (M4D Impact, 2014). The project is carried out by a Project Consortium consisting of different companies and Universities such as: Telefonica, Alcatel-Lucent,

Ericsson, University of Cantabria and the University of Surrey. The EkoBus Project envisions the deployment of 20,000 sensors in different European cities such as Belgrade and Pancevo (Serbia). 65 sensor nodes were deployed in two different locations measuring the 6 parameters of temperature, relative humidity, Carbon Monoxide (CO), Carbon Dioxide (CO₂), Nitrogen Dioxide (NO₂) and GPS location (Bielsa, 2012).

While these two big projects focus on monitoring either air or noise pollution, there is one project which combines the monitoring of air and noise quality simultaneously by using the sensor nodes produced by Libelium. Called Environmentally Friendly Urban Traffic Management (RESCATAME), it is carried out by a Consortium consisting of the following members: CARTIF, European BIC Network, Salamanca City Hall and Research Advisory Group P&G (Bielsa, 2011). This project is funded by the European Union through its LIFE programme. Its main goal is to achieve sustainable management of the traffic in the City of Salamanca by using two key elements: a pervasive air-quality sensors' network as well as prediction models. The project is collecting data to prove that, by using the data collected from the sensors located across the city (providing full time and geographical coverage at low cost), municipalities can efficiently achieve a way of better managing urban traffic in major European cities. 35 sensor nodes were deployed in two different locations measuring the 7 parameters of temperature, relative humidity, Carbon Monoxide (CO), Nitrogen Dioxide (NO₂), Ozone (O₃), Noise and Particles. Typically, the three big projects described above use the WSN arrangement as shown in Figure 2-9.

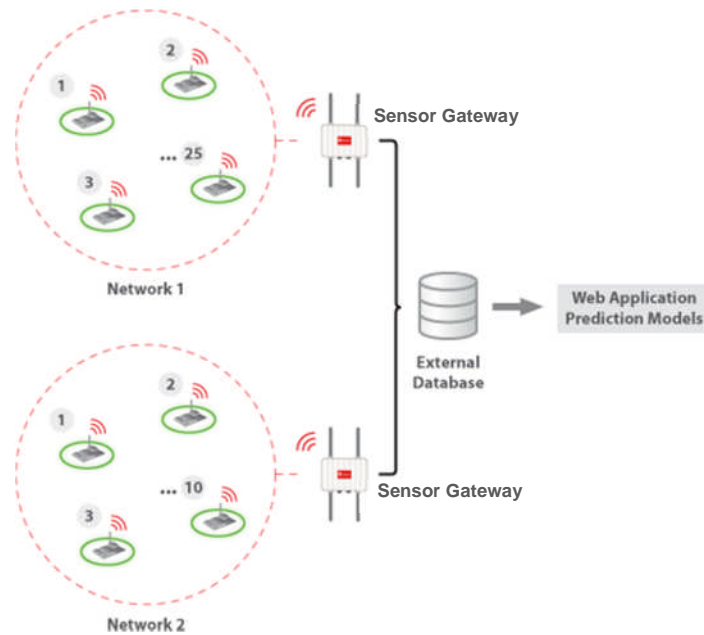


Figure 2-9 Libelium WSN arrangement

In a comparison with the Brüel & Kjær Sound & Vibration Measurement A/S, the Libelium WSN offers more flexibility in controlling the application of it, although it is easier to use the sensor Brüel & Kjær Sound & Vibration Measurement A/S as it is based on the “plug and play” concept and data can be accessed through the web browser; however, it is difficult for the user to integrate it with other systems. This is because users will not obtain any authority to manipulate the interface through the programming system. The Libelium WSN, on the other hand, offers a development kit rather than the completed end product. It is definitely not easy to assemble this kit and to carry out the computer programming, but the user will gain full control over the systems and components. The users also have the opportunity to add and remove sensors and write their own programme script to be uploaded to the system. Therefore, it is more practical to use the Libelium WSN for the development of a totally new mobile environmental management information system (MEIS).

The above mentioned works have demonstrated the ability of technological based surveillance to fill the gap left by physical observation/inspection and environmental monitoring (measurements). However, from this research’s point of view, similar to the relationship between physical surveillance and environmental monitoring (measurement), the use of technological and physical surveillance for environmental management at construction sites, in some situations, complements each other. For

instance, an air quality monitoring station might detect an air pollution problem due to the high quantity of Total Suspended Particulates (TSP) in air sampling. However, it would only indicate the existence of the problem without informing as to the source of the pollution (International Network for Environmental Compliance and Enforcement (INECE), 2009). An early assumption is that such a problem might be due to vehicles' movement, open burning activities, poor management of earth stockpiles, etc. Thus, the inspector has to carry out a physical inspection so that the source of the pollution can be identified. Subsequently, all relevant parties will need to be notified of this matter so that rectification works can be undertaken accordingly. Nevertheless, this is not to disregard the fact that the introduction of audio-visual surveillance via live video streaming would give the same effect as physical surveillance to some extent. However, a camera cannot cover the entire space of a construction site in a single view (Lee et al., 2011), hence requiring the deployment of many cameras with the functions of pan angle, tilt angle and zoom to ensure full coverage of a surveillance site. As a result, this might not be economical to deploy on site due to the cost and maintenance of the cameras and the system. Therefore, it could be better for the proposed mobile environmental information from environmental surveillance on construction sites to capitalise the advantages of these two approaches: physical surveillance (observation/walk-through inspection) and technological based surveillance (wireless sensor networks). In line with this argument, the International Network for Environmental Compliance and Enforcement (INECE) (2009) has made a comparison on information from both approaches and it is clearly shows that both approaches should complement each other (see Table 2-10).

Table 2-10 Comparing sources of compliance information (International Network for Environmental Compliance and Enforcement (INECE), 2009)

Information Source	Advantages	Disadvantages
Inspections	Provide the most relevant and reliable information.	Can be very resource-intensive.
Monitoring Environmental Conditions Near a Facility	Useful for detecting possible violations without entering the facility. Useful for determining	Can be difficult to demonstrate a connection between the pollution detected and a specific

Information Source	Advantages	Disadvantages
	whether permit or license requirements are providing adequate environmental protection.	source. Resource-intensive in areas of multiple sources.

2.5. SUMMARY

This review shows that the construction industry contributes to environmental degradation and, within the context of Malaysia, ‘Transportation Resources’, ‘Noise Pollution’, and ‘Dust Generation by Construction Machinery’ are the most risky environmental impacts on construction sites in Malaysia. Even though these negative impacts can be controlled and reduced through frequent surveillance by an environmental management team, traditional physical environmental surveillance and monitoring have some drawbacks as they are certainly challenging, time consuming, labour-intensive and can involve deficiencies and discrepancies (Vivoni and Camilli, 2003, Kim et al., 2008, Damian et al., 2007, Mohamad and Aripin, 2006). In an attempt to overcome these disadvantages, technological based surveillance has become an alternative but, again, in some circumstances it can be difficult to demonstrate a connection between the pollution detected and a specific source. Thus, physical environmental surveillance still remains important but some improvements can be made through the application of technologies and the use of technological base surveillance which can enhance the quantifying and representation of information on the physical, chemical and biological characteristics of the monitoring parameters.

As many researchers (Bowden, 2005, Nourbakhsh et al., 2012, Kim et al., 2008, Cox et al., 2002, Moe et al., 2004) have shown, the use of mobile devices has significantly improved reporting and communication in site inspection while other researchers (Zúniga and Krishnamachari, 2003, Ghobakhlou et al., 2011, Santini et al., 2008, Xianfeng et al., 2010, Abraham and Pandian, 2013) have implemented technological based surveillance by using wireless sensors and the Web as an alternative to traditional

environmental quality monitoring. It is a possible solution to have a mobile system that can accommodate physical and technological based environmental surveillance in one venue.

Therefore, based on the reviews and on an understanding of environmental surveillance on construction sites, any proposed mobile environmental information system should take on board the following:

- i. Environmental information should be concise, to-the-point and timely;
- ii. Environmental physical and technological based surveillance should be carry out in an integrated manner;
- iii. A tool or a system should be provided that enables an environmental officer to monitor, control and gain access to specific environmental information to ensure that the management of the works is carried out in accordance with all statutory requirements, best practice guidelines and the requirements of the Construction Environmental Management Plan (CEMP);
- iv. There should be the ability to make an informed decision based on the instant access to information;
- v. There should be an improvement in the time it takes to deliver information in the current systems;

In order to address these issues, the next chapter will discuss the mobile web and devices and the enabling technologies; all of which have a role to play in an effective information system for environmental surveillance.

CHAPTER 3. MOBILE ENVIRONMENTAL INFORMATION SYSTEMS

3.1. INTRODUCTION

The literature review in the previous chapter pointed out that traditional physical environmental surveillance and monitoring (measurement), and even technological based surveillance have some drawbacks which relate to the poor delivery of environmental information. As information issues remain central to the challenge of environmental protection (Chiabai et al., 2013), any initiatives including environmental surveillance requires environmental information that is concise, to-the-point, timely and usable (United Nations Human Settlements Programme (UN-HABITAT), 2008). However, the drawbacks that exist create an obstacle on environmental initiatives to obtain the information in desired forms.

New Information and Communication Technologies (ICT) may present appropriate tools that can support environmental research and its transmission to policy-makers and construction industry players. Cheap and ubiquitous Internet connectivity, the constantly enhanced technology of mobile communication devices as well as the advancements in sensory technologies (e.g. wireless sensor networks, radio-frequency identification, Global Positioning System (GPS) etc.) all adds up to technology advances which are expanding the boundaries of the Internet. Such a combination links the physical world to cyberspace through smart devices which have resulted in more and more smart processes and services which are possible and which can support environment protection initiatives.

The Internet has evolved and grows in importance, creating new value through its expansion and added utilisation. Thus, the vision of Internet connectivity has changed from “**any-time, any-place**” for “**any-one**” into “**any-time, any-place**” for “**any-thing**”. Such connectivity matches with the need for the delivery of concise, to-the-point, timely and usable environmental information.

3.2. THE USE OF IT FOR ENVIRONMENTAL SURVEILLANCE

Over a number of years, Environmental Information Systems (EIS) have been deployed worldwide in a variety of shapes and forms assisting environmentalists in their tasks. EIS is a generic term that describes the group of information technology (IT) systems that engage in one or more of the following purposes: environmental monitoring, data storage and access, disaster description and response, environmental reporting, planning and simulation, modelling and decision-making (Athanasiadis and Mitkas, 2004). These systems capitalise on the advantages and intelligent features of Information Technology (IT) in order to provide more accurate and timely environmental information.

One of the early examples of EIS is INFOTERRA which evolved in the 1970s. According to Spencer (1995), INFOTERRA was established in response to a recommendation of the United Nations Conference on the Human Environment. This system essentially provided information such as references to useful material, particularly environmental information, and the contact details of experts around the world who were willing to respond to INFOTERRA requests for information.

In the early 1980s, the United Nations Environment Programme (UNEP) developed a system to co-ordinate the range of environmental data sets that were held by UNEP and other associated organisations by using a common geographical reference system. Better known as the 'Global Resource Information Database' (GRID), it uses images, maps and tables derived from data acquired by satellite sensors, aerial reconnaissance and ground surveillance. It then processes and stores data in a way to make them easily accessible and comparable, using several complementary computer hardwares, Geographical Information System (GIS) and image-processing software system in its core in order to provide geographical referencing. (Mooneyhan, 1993).

The growth in the use of GIS in EIS has been on-going and, in addition, there were attempts also to use the Internet or the World Wide Web in the 1990s. This was caused by an effort to deliver EIS to a wider audience so as to address the Sustainable Development Public Participation issues which arose from the Earth Summit in Rio de Janeiro in 1992. However, in the 1990s, access to technologies such as the Internet and computers was expensive and computer skills' levels among the public were low. Furthermore, the estimated users of computers in 1999 represented only about 4-6% of the world's population and, of this figure, almost 90% was made up of Europeans and

North Americans (Jones, 2001). All these factors caused a limitation to the utilisation of the Internet as a medium of communication during that period.

In the millennium era, EIS incorporated domain knowledge and their reasoning functionalities have been utilised in the form of expert systems, case-based reasoning, or knowledge bases. For example, the New Zealand Distributed Information System (NZDIS) was designed to provide an open, agent-based environment for the integration of disparate sources of environmental information. In doing so, the NZDIS has an ability to perform integrated queries in an open distributed environment that can access a heterogeneous collection of environmental information sources (Purvis et al., 2003). Another example is the UWEDAT environmental data management and monitoring system. Mainly used in the field of ambient air quality monitoring, the UWEDAT was developed to fulfil Indonesian air quality monitoring tasks within the 'Blue Sky Programme' (Schimak, 2003). This system has provided Indonesia with 10 central hosts and networks within their major cities and about 50 measuring stations spread throughout their territory. This system has a tool for reporting or for web publishing and the users have access to air quality monitoring data via web interfaces. Furthermore, the web interfaces are flexible and transparent so that the system administrator can integrate the UWEDAT system into other environmental networks or information systems having a similar structure. This provides a solution to the integration problems faced by the early environmental information systems as has been discussed by Denzer and Güttler (1995)(cited in (Denzer et al., 2000).

The United Nations Human Settlements Programme (UN-HABITAT) (2008) has suggested that system hardware such as desktop computer hardware, plotter, scanner, printer, digitiser, a global positioning system (GPS) and other such items should be used in EIS. Typically, EIS in 20th and early 21st century used almost the similar system components that are shown in Figure 3-1. However, it is important to note that, even though the dissemination of information at this point in time had been improved, still the source of information for some parts of the system was relying on traditional methods. For example, the work of Hamoda (2008) and Ng (2000) showed that the environmental quality monitoring data for their research project came from digital data loggers instead of wireless sensors. They needed to manually download the collected information to a computer database where it could be viewed, manipulated and distributed electronically. Therefore, such a system did not allow users to get immediate

feedback from the system. It increased the possibility of typographical errors, causing inconsistencies in the information as well as a loss of information in some instances (Barrenetxea et al., 2008b).

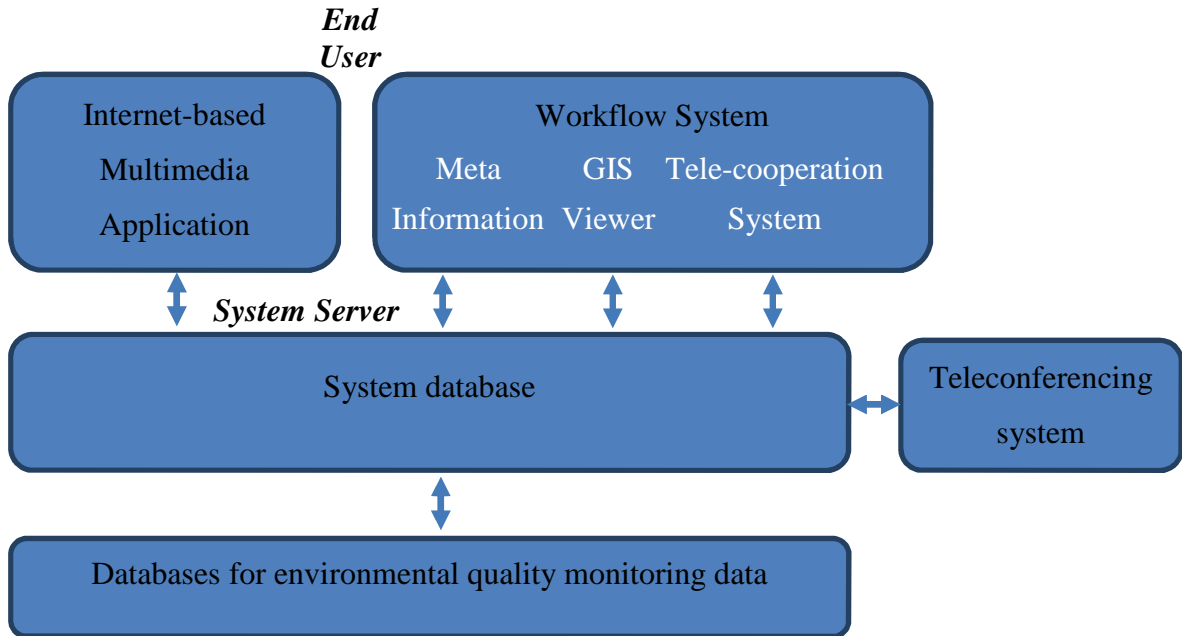


Figure 3-1 EIS System Components (modified from (Denzer et al., 2000))

Furthermore, all these systems are basically systems on Internet-enabled desktop computers and are fundamentally different from what is being offered by the Internet of Things. According to Pitt et al. (2011), these systems take a longer system initiation (e.g., booting the PC, followed by initiating the programme), are less intuitive than mobile devices (e.g. Personal Digital Assistants (PDAs) and mobile (or cellular) phones) and, most importantly, they are not intended to be carried as they are typically placed at a fixed location with a dependent network.

3.3. THE INTERNET OF THINGS

The next wave in the era of computing will be outside the realm of the traditional desktop because society is moving towards an “always connected” paradigm through numerous technological advances (Coetzee and Eksteen, 2011). This new paradigm seeks to enhance the traditional Internet into a smart Internet of Things (IoT) created around intelligent interconnections of diverse objects in the physical world (Minoli, 2013). As a result, many “Intranets” of Things are evolving into a much more integrated and heterogeneous system (Zorzi et al., 2010, Gubbi et al., 2013) and the Internet is extending into the real world embracing everyday objects (Hu et al., 2013a, Mattern and Floerkemeier, 2010). In discussing the evolution, Park et al. (2014) had described that the “Intranets” of Things is a local network of a set of things such as wireless sensor networks (WSNs), machine-to-machine (M2M), smart homes whereas the in IoT, those things would be connected each other by the Internet and its could support smart services and applications by/for diverse service providers with a wide range of Intranets of Things. Thus, according to Park et al. (2014), the “Intranets” of Things can only extract regional information containing a specific content from the things while IoT could provide large scale, comprehensive, and historical information by collaborating between different Intranets of Things even if they have heterogeneity regarding devices, local communication technologies, and deployment goals.

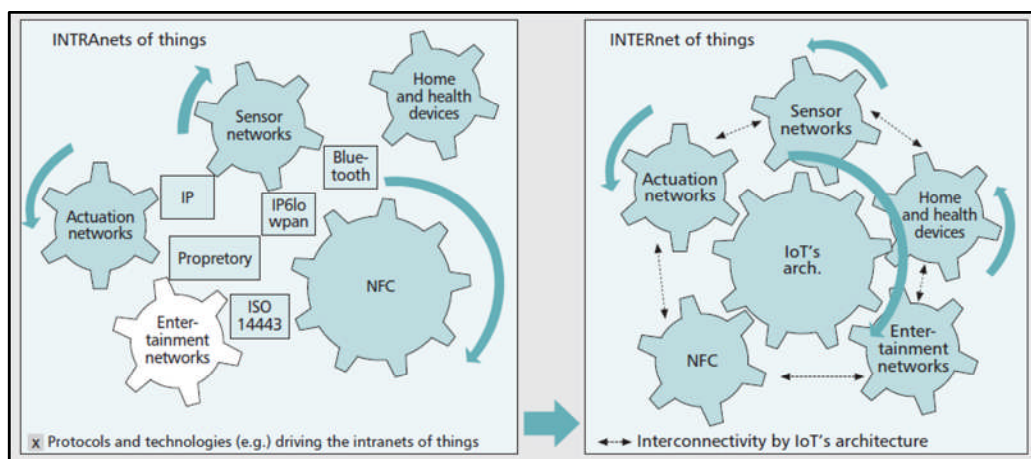


Figure 3-2 The Evolution of “Intranets of Things” to the “Internet of Things.”(Zorzi et al., 2010)

In 2009, a dedicated EU Commission action plan ultimately saw the Internet of Things (IoT) as a general evolution of the Internet “from a network of interconnected computers to a network of interconnected objects” (Mattern and Floerkemeier, 2010). The “Internet of Things” describes a vision where environmental and daily life items become part of the Internet (Coetzee and Eksteen, 2011). These environmental and daily life items, also named “things”, “objects”, or “machines” (Chaouchi, 2013) include, but are not limited to, machinery, home appliances, vehicles, individual persons, pets, cattle, animals, habitats, habitat occupants, as well as enterprises (Minoli, 2013). To become part of the Internet, the “things” are enhanced with computing and communication technology and join the communication framework (Chaouchi, 2013). Interactions are achieved utilizing a plethora of possibly different networks, computerized devices of various functions, form factors, sizes, and capabilities such as iPads, smartphones, monitoring nodes, sensors, and tags, and a gamut of host application servers (Minoli, 2013).

With the IoT, a new dimension has been added to the world of information and communication technologies: from anytime, anyplace connectivity for anyone, we will have connectivity for “anything” (International Telecommunication Union (ITU), 2005). By adding the “anything” connection axis, new sources of information are introduced into the connected network and this enables access to new services exploiting the newly-introduced information in the network (Chaouchi, 2013). These services can transform the processed information into knowledge for the benefit of mankind and society. Accurate information about the status, location and identity of things which form part of, and impact on, the environment allows for smarter decision making and appropriate action taking (Coetzee and Eksteen, 2011).

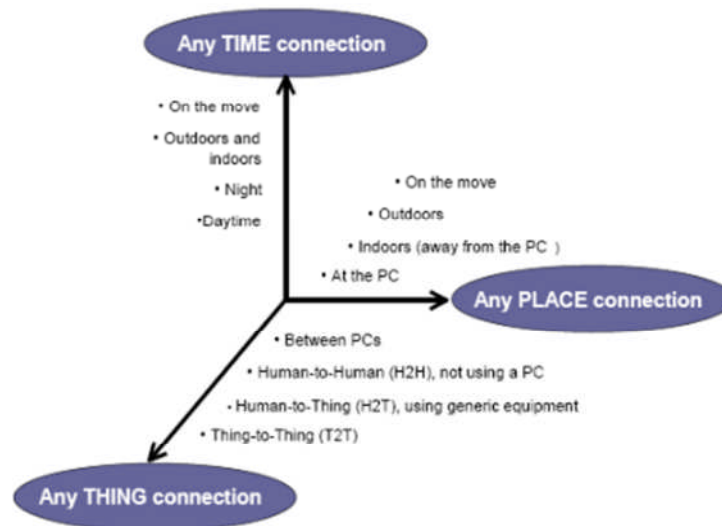


Figure 3-3 ITU: Vision of any place, any time and anything (International Telecommunication Union (ITU), 2005)

The IoT can also be described as a new-generation information network that enables seamless and continuous human-human, machine-to-machine and/or human-to-machine communication (Minoli, 2013, Jian et al., 2012). In the IoT, “smart things/objects” are expected to become active participants in business, information and social processes where they are enabled to interact and communicate amongst themselves and with the environment by exchanging data and information “sensed” about the environment, while reacting autonomously to the “real/physical world” events and influencing them by running processes that trigger actions and create services with or without direct human intervention (Vermesan et al., 2011).

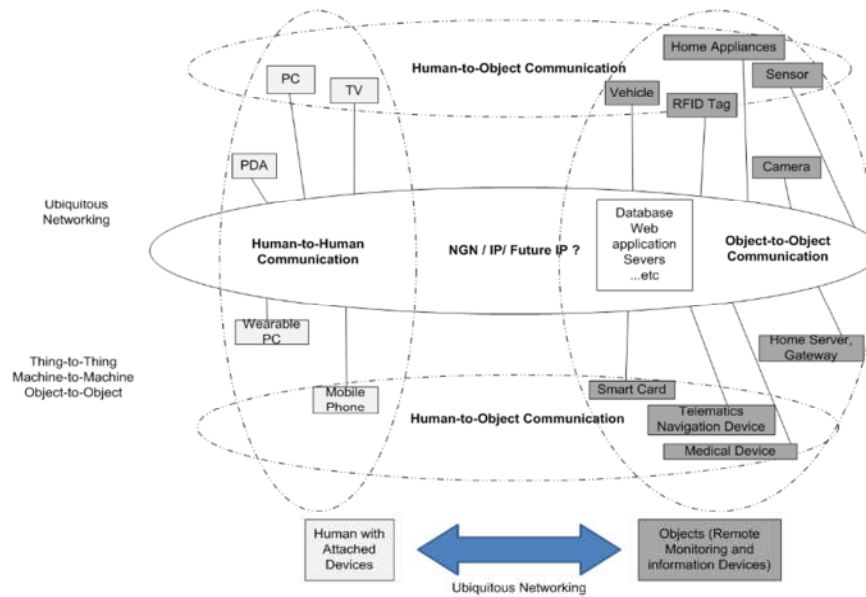


Figure 3-4 The Interaction Between Components in the Internet of Things (Chaouchi, 2013)

As shown in Figure 3-4, it can be seen that the Internet of Things infrastructure allows combinations of human beings, sensor technologies, smart objects (i.e., telematic navigation devices, smart cards, etc.), mobile device technologies and others. These entities or “things” can also be deployed in inaccessible or remote spaces (oil platforms, mines, forests, tunnels, pipes, etc.) or in cases of emergencies or hazardous situations (earthquakes, fire, floods, radiation areas, etc.) by using different but interoperable communication protocols and thus can realise a dynamic multimodal/heterogeneous network (Vermesan et al., 2011, Gubbi et al., 2013). Again, as has been mentioned earlier, the interconnections amongst these different entities or “things” will increase the value of information as they will discover and explore each other and learn to take advantage of each other’s data by the pooling of resources and dramatically enhancing the scope and reliability of the resulting services (Vermesan et al., 2011). Due to these advantages, several application domains will be impacted upon by the emerging Internet of Things and, to illustrate this, Gubbi et al. (2013) have produced an Internet of Things (IoT) Schematic to show some of the end users and the applications of IoT (Figure 3-5).

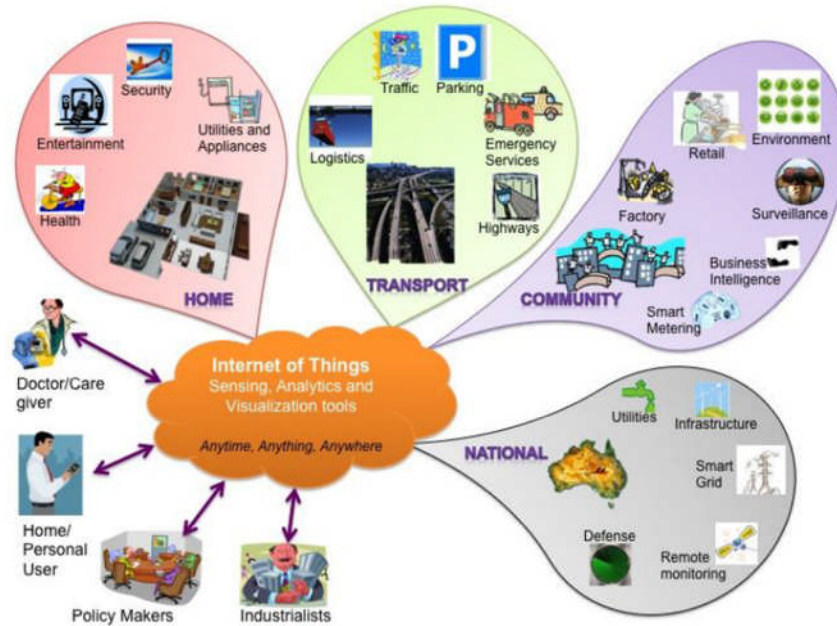


Figure 3-5 Application Domains of the Internet of Things (Gubbi et al., 2013)

Environmental management and surveillance is one of the application domains which are impacted upon by the Internet of Things. Therefore, the next section will discuss the application of a mobile web as a part of the Internet of Things for environmental management and surveillance which is the focus of this research.

3.4. MOBILE WEB FOR ENVIRONMENTAL SURVEILLANCE

Mobile devices nowadays have become an integrated part of daily life hence the role of the mobile device as a generic tool in everyday life has grown. According to a recent study by Kearney (2013), people use their mobile devices for everything from taking a photograph to browsing the Internet. Looking at Figure 3-6 it can be noted that voice calls are now fifth in the list of most used mobile applications (as measured by the average time spent using that application per day (12 minutes)). Top of the list is browsing the Internet at 25 minutes per day; more than twice as much as is spent on making calls (Figure 3-6). This illustrates how important the mobile web is to the smartphone user.

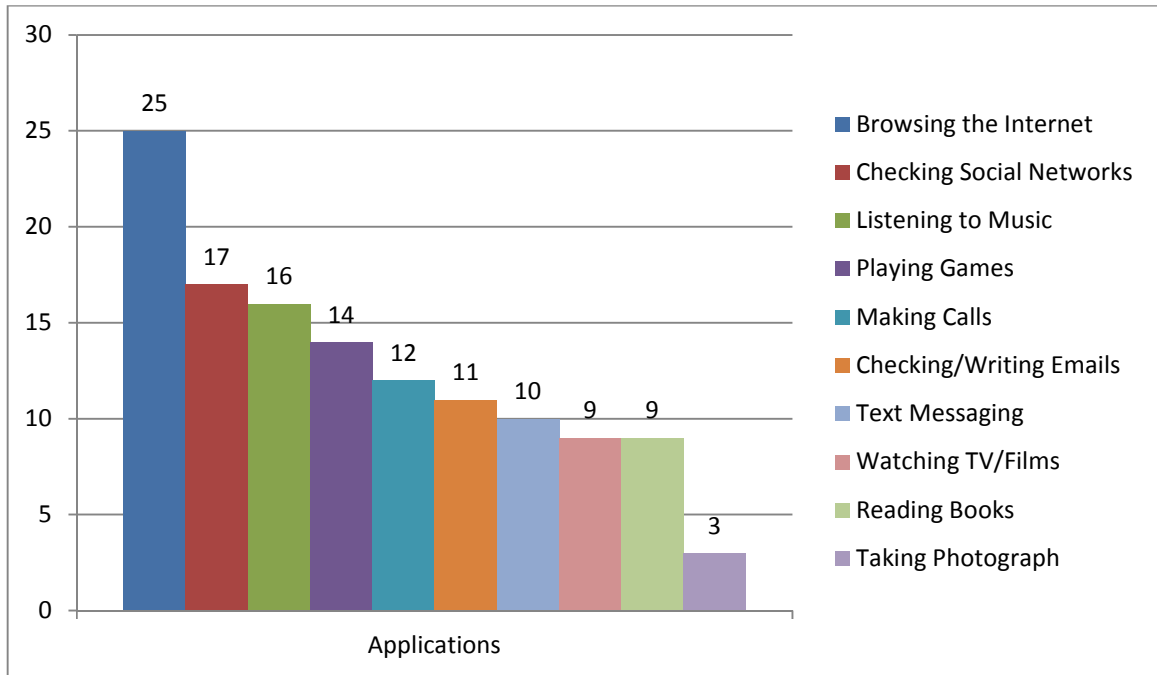


Figure 3-6 The Most Used Mobile Applications (Kearney, 2013)

In its analysis of Internet Trends, the banking giant Morgan Stanley has estimated that, by 2014, the number of mobile Internet users will surpass the number of fixed Internet users, as illustrated in Figure 3-7 (Morgan Stanley Research, cited in (Grayson et al., 2011)). This growth in mobile internet users is accompanied by the increasingly cheaper costs offered by the majority of mobile operators (Harno, 2010) and mobile broadband operators (Grayson et al., 2011). Thus, users can enjoy their monthly data allowances via their mobile subscriptions with Internet browsing by using modern smart phones which are more capable and sophisticated (Mydlarz, 2013). With the mobile broadband subscription rate of growth being greater than twice that of fixed network subscriptions, it is clear that the end of the next decade will see the Internet being dominated by mobile hosts (Grayson et al., 2011). This statistics are further supported by the fact that the advent of the smartphone, with the widespread deployment of mobile broadband networks, has led to an explosion of mobile data services.

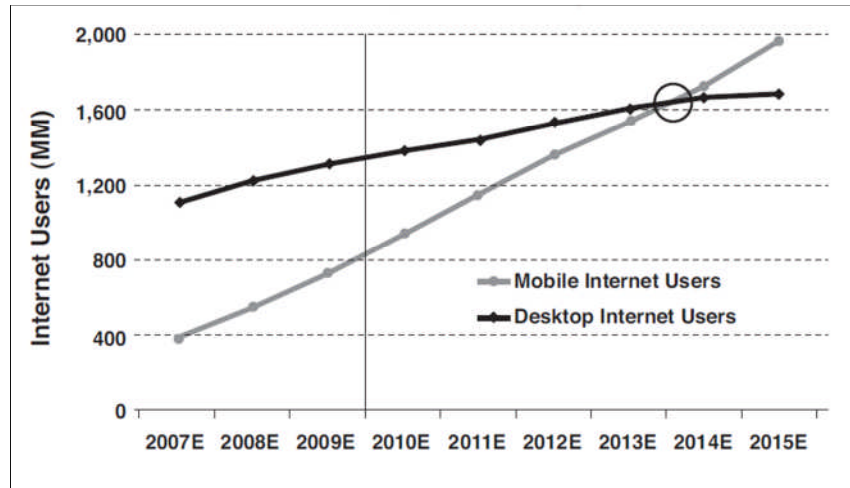


Figure 3-7 Global Mobile versus Desktop Internet User Projection, 2007-2015E (Morgan Stanley Research, cited in Grayson et al. 2011)

One logical development of the Internet of Things (IoT) is to leverage the World Wide Web and its many technologies as an infrastructure for smart objects including the mobile devices. Instead of conventional Web service technology, the Modern Web servers with a sufficient feature set (support for several simultaneous connections have an ability to transmit dynamically generated content and “server push” event reporting) need only a 8 kB memory and no operating system support thanks to clever cross-layer TCP/HTTP optimization (Mattern and Floerkemeier, 2010).

The development of the mobile web platform started with the introduction of the Wireless Application Protocol 1.0 (WAP 1.0) in 1998. The mobile web platform then evolved up to the current version which better known as Mobile Web 2.0 (Figure 3-8). The Mobile Web 2.0 is a platform whereby content and applications are no longer created and published by individuals, but instead are continuously modified by all users in a participatory and collaborative fashion (Kaplan and Haenlein, 2010). Blogs, wikis and collaborative projects are a few examples of the applications in Web 2.0 that replace the idea of content publishing (such as personal web pages and Encyclopaedia Britannica Online which belonged to the previous platform).



Figure 3-8 Evolution of the Mobile Web Platform (Firtman, 2010)

According to Mehta (2008), any website, whether it has been developed purposely to work on a mobile or not, which can be accessed from mobile devices like cell phones and PDAs is a mobile web. However, most scholars present different definitions of the mobile web. Jindal et al. (2008), for example, define the mobile web as the collection of a web of pages that are designed for, or are particularly suitable for, consumption on mobile wireless devices such as cellular phones. Jindal et al. further place emphasis on the web programming languages and the fact that the web pages of the mobile web are written in mark-up languages like CHTML, XHTML and WML whereas the fixed web contains sets of web pages written in HTML. In line with the above definition, the RDZ Media Group LLC (2011) explain that the mobile web differentiates from standard websites by the fact that a mobile website is designed for smaller handheld display and touch-screen interface. Thus, such a site takes advantage of utilising smaller screen real estate and vertical scrolling or tapping on the screen to replace the function of the mouse. Therefore, in the context of this research, the mobile web can be defined as a collection of web pages that have been designed and written in mark-up languages bearing in mind the limitations as well as the advantages of mobile devices.

Like any website, mobile websites come under one domain name or belong to one entity, may consist of several different pieces of content, such as text, images or multimedia, and can be heterogeneous in the technology used to integrate the content into the webpage. These websites can contain a set of web pages that are static in nature (through which users obtain information) or a more complex dynamic interaction where the user needs to contribute information to the system (I2Web Consortium, 2011).

This second type of application is known as “Dynamic Web”. A dynamic web page is a web page that displays different content each time it is viewed. It could include simple or complex forms or more complex web content. Basically, there are two types of dynamic web pages which are Client-Side Scripting and Server-Side Scripting.

The Client-Side Scripting Web pages are web pages that use client-side scripting languages such as JavaScript and Flash so that the site changes in response to an action within that web page, such as a mouse or a keyboard action (Doteasy Technology Inc., 2014). In such cases, the user's web browser would download the web page content from the server, process the code that is embedded in the web page and then display the updated content to the user. Whereas, the Server-Side Scripting Web pages are web pages that come with changeable content when a web page is loaded by using server-

side scripting. For example, login pages, forums, submission forms and shopping carts, all use server-side scripting since those web pages change according to what is submitted to them. Scripting languages such as PHP, HTML5, ASP, ASP.NET, JSP, ColdFusion and Perl allow a web page to respond to submission events.

The ability to interact dynamically makes a dynamic web become more exciting and, most importantly, it has an ability to utilise the advantages of mobile devices for the development of a mobile environmental information system (MEISs). Mehta (2008) for example, has demonstrated the ability of a dynamic mobile web to make a telephone call as easy as a single-click by adding a call link, as below, onto the web.

```
<a href="tel:+18007687669">+1-800-POTRNOW</a>
```

This method can be easily used to create a phonebook in the mobile web. Therefore the user can have the access to his contacts while using the system. In the application of the MEISs, the availability of a phonebook would help the Contractor's Environmental Coordinator to easily retrieve all his contact details and make a telephone call to other relevant personnel especially in the event of emergency.

The dynamic mobile web would also make it possible to retrieve the coordinates of the mobile devices' location by using a location-based service (LBS) which is a service based on the geographical positions of mobile handheld devices such as smartphones or tablet computers (Hand et al., 2006). The introduction of Geolocation, a feature of the HTML5 specification, and map APIs (Application Programming Interfaces) like Google Maps APIs has made the LBS construction easy (Hu et al., 2013b, Werdmuller, 2013). It can be used to pinpoint the user's location on a map without needing GPS support directly. Hu et al. (2013b) have used the `getCurrentPosition` or `watchPosition` method to get the user's position and the example of the script used is as follows:

```
<!DOCTYPE html>
<html>
<body>
&nbsp; &nbsp; ID: <input type="text" size="4" id="id" value="1" /> &nbsp;
<button onClick="getLocation( )">Update Location!</button>
<p><div id="myDiv"></div></p>
<script>
var x = document.getElementById( "myDiv" );
var id = document.getElementById( "id" ).value;
function sendLocation( position ) {
```

```

var url = "updateLocation.php?id=" + id +
"&lat=" + position.coords.latitude +
"&long=" + position.coords.longitude;
window.open( url, "_self" ); // Calling updateLocation.php
}
</script>
</body>
</html>

```

It has been discussed in Section 2.4.3., the traditional method of surveillance is susceptible to georeferencing errors (Vivoni and Camilli, 2003, Kim et al., 2008). With the combination of this Geolocation feature and PHP, the MEISs can automatically find the location of the user and store the coordinates of Latitude and Longitude into the database. Even though the accuracy of the coordinates is arguable, this information might at least help the inspector to clearly locate the area where the non-compliance occurred during the physical surveillance.

In addition, it has generally been concluded that inspectors are still wishing to rely on a checklist to perform physical surveillance. The paper form checklist actually can be converted into a digital version by making it available on the mobile web. The submission forms can be created by using a HTML. The users have to enter the data, then submit them online to load entry into the database. In this event, the POST method will be used and the PHP file is required to upload the data to the database. In addition, Lengstorf (2009) has also demonstrated the use of the GET method in order to display entry on the web. Therefore, with the combination of POST and GET methods, users may enter, save, retrieve and display data on the mobile web. Lengstorf (2009) has provided an example of the HTML script that can be used to create the submission form, as given below.

```

<!DOCTYPE html
PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN"
"http://www.w3.org/TR/xhtml1/DTD/xhtml1-strict.dtd">
<html xmlns="http://www.w3.org/1999/xhtml" xml:lang="en" lang="en">
<head>
<meta http-equiv="Content-Type"
content="text/html; charset=utf-8" />
<title> Simple Blog </title>
</head>
<body>
<h1> Simple Blog Application </h1>

```

```

<form method="post" action="inc/update.inc.php">
<fieldset>
<legend>New Entry Submission</legend>
<label>Title
<input type="text" name="title" maxlength="150" />
</label>
<label>Entry
<textarea name="entry" cols="45" rows="10"></textarea>
</label>
<input type="submit" name="submit" value="Save Entry" />
<input type="submit" name="submit" value="Cancel" />
</fieldset>
</form>
</body>
</html>

```

The Internet has traditionally been used to share static content but recent technologies have allowed information to be shared in real-time. According to Lengstorf and Leggetter (2013), the term ‘real-time’ refers to the timely nature between an event’s occurrence and our being made aware of it. Lengstorf and Leggetter elaborate further that the event needs to be delivered in a short enough amount of time for that event to still be relevant; to still have meaning within the context to which it applies.

The introduction of Websockets as a part of HTML5 (Lengstorf and Leggetter, 2013) and Node.js as an event driven javascript framework (Guarini, 2013, Nguyen, 2012) has a direct application to real-time web technologies and client server communication. The ability of the Web to display data in real-time is very important especially in the area of environmental monitoring. The sensors may be able to send data to the database in a short time, however, immediate data display on the web is also equally important in order to maintain the value and impact of such data on the performance of the overall system. These two components, however, require a special dedicated hosted service like Pusher, Clever-cloud, AppFog etc. as the normal web hosting server is not compatible.

All of these characteristics have shown that the mobile web has the ability and practical to be used for the development of the mobile environment information systems (MEISs). However, for a better understanding of mobile environment information systems (MEISs), it is best to describe the architecture concerned to gain an idea as to how it is typically setup and works. As a part of the IoT, the mobile web works together with other entities to form a network of interconnected objects in order to deliver tasks

as desired by the user. Thus, the next section will discuss in the detail the architecture of the IoT.

3.5. THE ARCHITECTURE OF THE IOT

All Web sites have information architecture (IA). According to Rosenfeld and Morville (2002), there is no single definition for IA; thus they define the IA as follows:

1. The structural design of shared information environments.
2. The combination of organization, labelling, search and navigation systems within web sites and intranets.
3. The art and science of shaping information products and experiences to support usability and findability.
4. An emerging discipline and community of practice focused on bringing principles of design and architecture to the digital landscape.

In terms of the architecture of the IoT, it should be an open architecture using open protocols to support a variety of existing network applications with some scalability, security and semantic representation middleware to promote data world integration with the Internet. Therefore, by summing up some research work within the literature by Fang et al. (2014), Jian et al. (2012), Sarma and Girão (2009), Freeman and Simi (2011) and Castell et al. (2014), this research comes to the conclusion that the architecture of the IoT should be a four-layer structure, it should contain a sensing and control layer, a networking layer, a middleware layer and an application layer. Figure 3-9 shows illustration of the Architecture of the IoT.

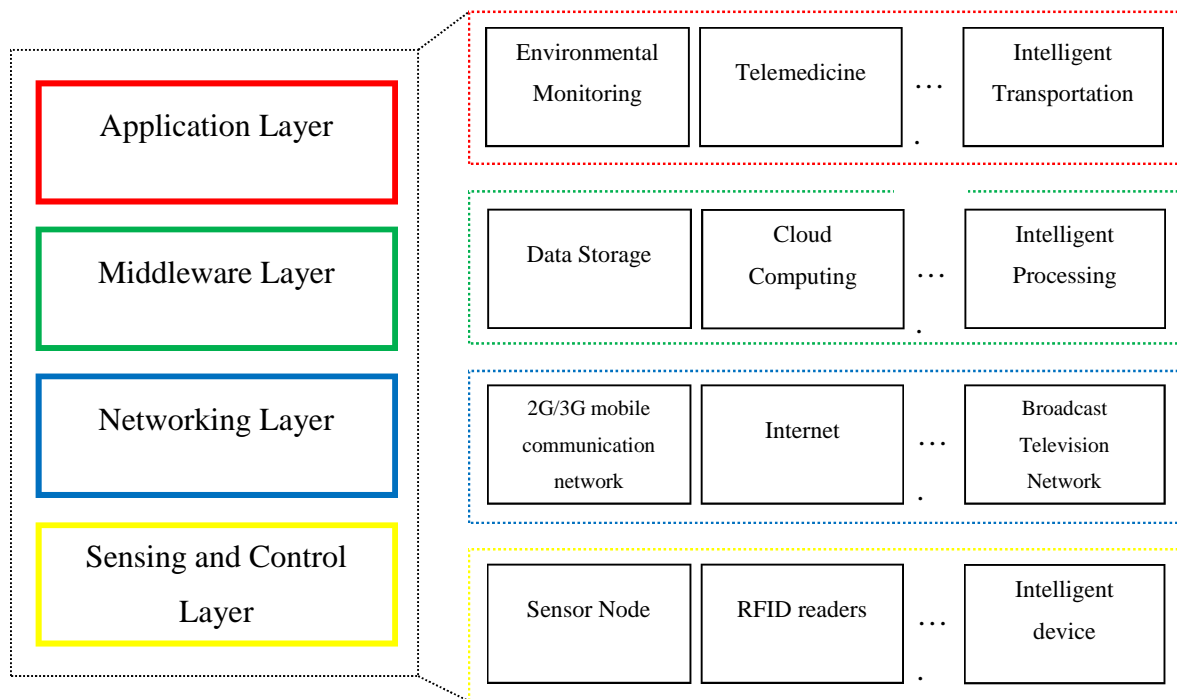


Figure 3-9 The Architecture of the IoT (Jian et al., 2012)

3.5.1. THE SENSING AND CONTROL LAYER

The sensing and control layer provides the foundation of the development and application of the IoT. The components of this layer would include any RFID readers, smart sensor nodes and access gateways, etc. These components have an ability to sense the relevant information within the target environment and pass it to the nearest gateway. The gateway then submits the collected data via the Internet to the background processing platform.

3.5.2. THE NETWORKING LAYER

The IoT requires network integration, routing, format conversion, address conversion, etc. The networking layer holds the responsibility for the different types of networks' integration, such as the Internet, Mobile Communications Network and Broadcast Television Network.

3.5.3. THE MIDDLEWARE LAYER

This layer provides for the initialization of resources, monitoring the operation status of resources, coordination of work between various resources and achieving cross domain interactions between resources. In addition, this layer is an important component within information processing as it realizes reasoning and the semantic understanding of sensing data. Because the user needs to store, organise content and contextualise the data as a block, the user can rely on the capabilities of this layer in providing data queries, storage, analysis, mining, etc.

3.5.4. THE APPLICATION LAYER

After analysing and processing the sensing data, the application layer uses these data to provide users with a variety of different types of services. The IoT application can be divided into network monitoring (logistics, pollution control), control type (intelligent transportation, intelligent household) and scanning type (mobile purse, drive through to pay highway toll fees), etc.

3.6. MOBILE DEVICES AS MEDIATOR BETWEEN PEOPLE, THINGS AND THE INTERNET

Steadily declining prices for both cellular and broadband services in parallel with consistent updates within the latest technologies has resulted in unprecedented growth in 3G uptake and the growth of the mobile devices' segment in the global ICT market. Globally, the average price per unit of speed (Mbps) has decreased significantly between 2008 and 2012, with the global median price of USD 19.50 per Mbps in 2012, almost a quarter of the price that was being charged in 2008 (International Telecommunication Union (ITU), 2013). Meanwhile, looking at the purchasing cost of the smartphone in Malaysia, for example, the Nokia Lumia 525 is three times cheaper (RM550) now compared to the Nokia N70 in 2004 (RM1,800) (MobileMegaMall, 2014, Melayu.com, 2005). This brings value for money as the Nokia Lumia 525 has better features such as a bigger display screen with a touch screen, higher RAM, higher camera resolution etc. These scenarios have caused mobile broadband connections over 3G and 3G+ networks to enjoy an average growth of 40% per year and 50% of people

worldwide are now covered by their networks (International Telecommunication Union (ITU), 2013).

The growth of the mobile device segment in the global ICT market has also perhaps transformed the way in which people and organisations communicate and interact by creating mobility in communication as long as they have access to their mobile devices. It means that a user can use devices to communicate at “anytime, anywhere, with anyone” while connecting to the network (Fathi, 2009, Carswell, 2008, Basole, 2004). Mobile devices are indeed becoming an integrated part of daily life hence the role of the mobile device as a generic tool in everyday life has grown and, not surprisingly, mobile devices also can take on the role of intermediaries between people, everyday items and the Internet (Mattern and Floerkemeier, 2010).

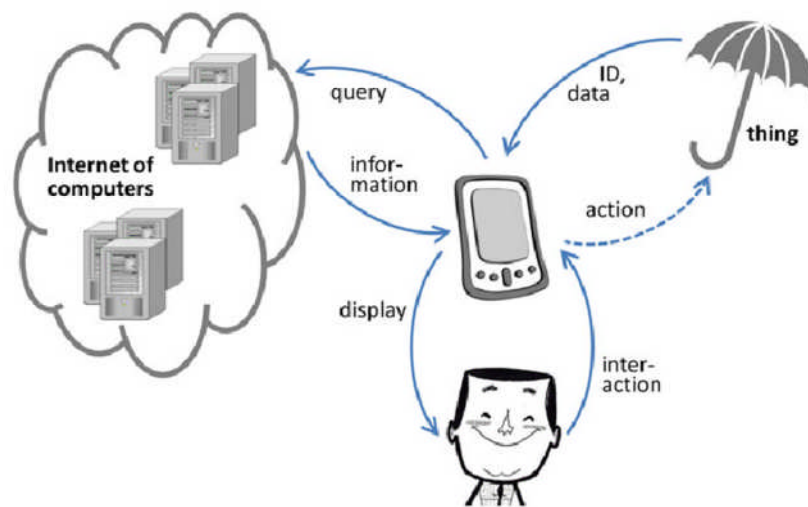


Figure 3-10 The mobile devices as intermediaries between people, everyday items and the Internet (Mattern and Floerkemeier, 2010)

The role of mobile devices should also reflect their ability to handle complex functions and services while supporting the needs of an Environmental Officer as a ‘mobile worker’. According to Bowden (2005), an Environmental, Safety and Health (EHS) Officer is a ‘mobile worker’ because he will normally use a mobile device (e.g. a handheld computer or digital pen) whilst moving around or remaining stationary for

short periods of time. The communication infrastructure can be provided by either a WLAN providing coverage in the area of work or a mobile (radio or telephone) network. If the worker simply collects the data whilst mobile and then goes back to his desk to synchronise the information, he then becomes a fixed worker. Bowden has also suggested that the construction industry should utilise the advantages and features of mobile devices to enhance communication among relevant parties.

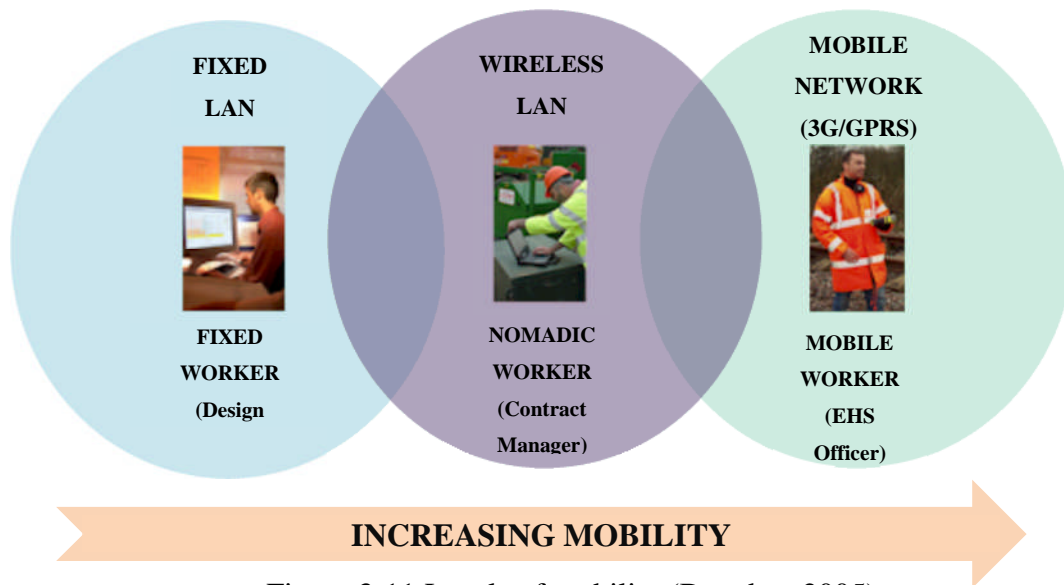


Figure 3-11 Levels of mobility (Bowden, 2005)

Klopfer et al. (2002) suggest that, in order to fully capitalise the use of mobile devices for environmental management, the features of mobile devices should be harnessed including:

- Portability – able to bring mobile devices to different sites and move around within a site;
- Social interactivity – can share information and collaborate with other people face to face;
- Context sensitivity – can get a hold of data unique to the current location, environment and time, including both real and simulated data;
- Connectivity – can connect handhelds to data collection devices, to other handhelds and to a common network that creates a true shared environment;

- Individuality – can provide unique scaffolding that is customised to the individual’s path of investigation.

More and more organizations and people are discovering how mobile phones can be used to gain social impact, including how to use mobile technology for environmental protection, for sensing and to leverage just-in-time information to make our movements and actions more environmentally friendly. Khan et al. (2013) have identified the areas which leverage on mobile phone sensing capabilities and one of them relate to the purpose of this research. Obviously other previous researches also have clearly proved that the mobile phone would facilitate the interactions of smart objects within the framework of environmental Internet of Things in the form of Human-to-Human communication, Human-to-Object communication and Object-to-Object Communication.

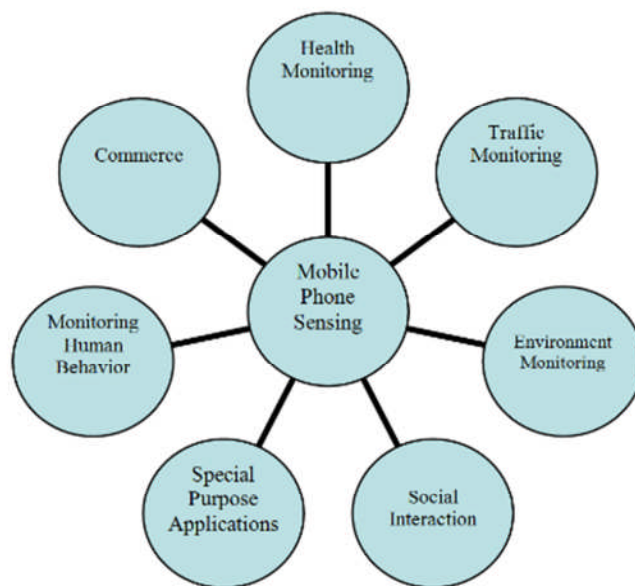


Figure 3-12 Areas leveraging on mobile phone capabilities (Khan et al., 2013)

With regards to the Human-to-Human communication, it is well known that the mobile phone is being developed as a tool to enable people to communicate between each other through the mediums such as phone calls, Short Messaging System (SMS) and emails. These mediums are very important in the process of environmental management especially in the event of non-conformance toward the environmental regulation or when an emergency occurred at the construction sites. The environmental inspector

would need to contact the project managers or team members and informed them about the problems so that the rectification works can be done (Greater London Authority, 2014). In addition, the phone's camera would adding some values by providing an important evidence associates to the problem that been happened. The Human-to-Human communication also exists in the situation where the users use inspection checklist and, generate and disseminate the report to the stakeholders through the mobile web or application on the mobile phones as demonstrated by (Kim et al., 2008).

Whereas for the Human-to-Object communication, previous researches have shown that the attributes of mobile phone would facilitate such communication. Kanjo (2010) for example, has developed the sound sensing system called NoiseSpy that turns the mobile phone into a low-cost data logger for monitoring environmental noise. It allows users to explore a city area while collaboratively visualizing noise levels in real-time. In addition to that, the geographical coordinates can be obtained using a combination of GPS (Global Positioning System) on the mobile phones, the cellular infrastructure and Wi-Fi networks (Hwang and Yu, 2012). This would enable the location-based services, allowing the detection of the exact whereabouts of its owner. And no less important, the existence of mobile web on the mobile phones would enable the display of the data and information which gathered from the mobile phone sensors and other smart objects such as wireless sensor networks, wireless weather station, RFID cards, camera, etc.

Last but not least, in term of Object-to-Object Communication, the mobile phones also have the capability to communicate with other smart objects. Rajitha and Swapna (2012) have demonstrated that the mobile phone would able to receive the message from the wireless sensor network via SMS (Short Messaging System). This functionality is very important in setting up the early warning alert system as the system can automatically alert the people by sending the message and alert the people to take the necessary preventive action against any unexpected bad situation (RPS Group, 2015).

It is expected through the interactions of the smart objects within these three forms via the mobile phone could enhance communication and enrich the information given to the user. Furthermore, the affordable ownership cost and the portability of the mobile phone would suit to the need of an Environmental Officer as a 'mobile worker' as described by

Bowden (2005), hence make it suitable as a mediator within the environmental Internet of Things.

3.6.1. THE CHARACTERISTICS OF MOBILE DEVICES

Firtman (2010) has categorised mobile devices as mobile phones, low-end devices, mid-end devices, high-end devices, smartphones, non-phone devices, small personal object technology (SPOTs), tablets, netbooks and notebooks. Firtman has also classified mobile devices as portable, personal, staying with the user almost all the time, easy and fast to use and as having a network connection.

As compared to the internet-enabled computer, it is easier to use mobile devices because they can be easily configurable (home screens, preferences) and have less sophistication (common interfaces, a highly-sensitive touch interface, single API). For further understanding, it is useful to know in detail the characteristics of mobile devices in terms of display, resolution, physical dimensions, aspect ratio, input methods, geo-location, phone calls, Short Message Service (SMS), Multimedia Message Service (MMS) and application installation. Firtman (2010) provides details on the characteristics of mobile devices as shown in Table 3-1.

Table 3-1 The Characteristics of Mobile Devices (Firtman, 2010)

Nos.	Characteristics	Description
1	Display	A mobile device has about 1.5, 2.3, or 3 inches' screen sizes (diagonally). Relatively, it has a very small screen as compared with a desktop.
2	Resolution	<p>The resolution for the devices can be separated into four basic groups:</p> <ul style="list-style-type: none"> • Low-end devices: 128×160 or 128×128 pixels • Mid-end devices (group #1): 176×220 or 176×208 pixels • Mid-end devices (group #2) and high-end devices: 240×320 pixels • Touch-enabled high-end devices and smartphones:

Nos.	Characteristics	Description
		240×480, 320×480, 360×480, 480×800, 480×854, or 640×960 pixels
3	Physical dimensions	Physical dimensions refer to the relationship between screen size and resolution which is known as the PPI (pixels per inch) or DPI (dots per inch). In June 2010, Apple presented iPhone 4, the first device with a “retina display,” that is a display with 326 pixels per inch (ppi). The human retina has a limit of 300 ppi at a certain distance, thus iPhone 4 with 960×640 in landscape mode has more pixels per inch.
4	Aspect ratio	A device’s aspect ratio refers to the ratio between its longer and shorter dimensions. There are devices with vertical (or portrait) and horizontal (or landscape) aspects and there are also some square screens. Many come with rotation capabilities. Such a device can be either 320×240 or 240×320, depending on the orientation.
5	Input methods	<p>There are many different input methods for mobile devices such as: -</p> <ul style="list-style-type: none"> • Numeric keypad • Alphanumeric keypad (ABC or QWERTY) • Virtual keypad on screen • Touch • Multi-touch • External keypad (wireless or not) • Handwriting recognition • Voice recognition <p>One device may support only one input method or a combination of these, like a touch device with an optional onscreen keyboard and also a full QWERTY</p>

Nos.	Characteristics	Description
		physical keyboard.
6	Geo-location	Many devices are equipped with location-based services' technology such as a Global Positioning System (GPS), an Assisted Global Positioning System (A-GPS), a WiFi Positioning System (WPS) or cell-based location tracking.
7	Connectivity	Each mobile device has several types of connectivity options. As a basic, many mobile devices have GPS, Bluetooth, Wi-Fi, 3G and even 4G connection. However, as technology keeps on improving, the latest mobile devices like the Samsung Galaxy S4, for example, have two of the latest connectivity options such as Near-Field Communication (NFC) and MHL. The NFC is used to connect phones and tablets with audio docks, such as the Samsung GA-F61, while the MHL is a technology that is crammed into the microUSB slot of the Samsung Galaxy S4. With the right adapter, it allows the phone to output HD video and surround sound to a TV using an HDMI cable.
8	Storage	Many mobile devices come in 16GB as standard with the option to expand the capability through a microSD memory card slot, while others may have 32GB and 64GB as standard.
9	Core Processing Unit (CPU) and GPU	Mobile devices may not have processors such as those on internet-enabled computers that can deal with complicated calculations or even have the RAM to hold the entire page before rendering it. However, a significant improvement has been made to the latest mobile devices. Samsung Galaxy S4 and Iphone 5, for example, have a Qualcomm Snapdragon 600 1.9GHz

Nos.	Characteristics	Description
		CPU with 2GB RAM and an Apple A6 dual-core 1.2GHz, 1GB RAM, PowerVR SGX 543 GPU respectively. This advancement will definitely improve mobile devices' ability in performing mobile computing.
10	Camera	Nowadays, the cameras that come installed on phones are capable of taking high quality photos. A phone is usually in a user's pocket and is light enough to carry around and capture events as quickly as they happen. Carrying around a large digital camera can sometimes require another backpack or carrying case. Furthermore, all pictures taken on the phone can be shared online via Instagram, Facebook, and a number of other social sites and apps or can even be sent through text.
11	Phone calls	Mobile devices can make phone calls.
12	Short Message Service (SMS)	Most devices allow users to create text messages, to send to other devices or to a server, with a length of up to 160 7-bit ASCII characters (or 140 8-bit ASCII characters, or 70 Unicode chars), or to concatenate many messages for a larger text.
13	Multimedia Message Service (MMS)	Mobile devices often allow users to create messages with text and attachments, such as images, videos or documents.
14	Application installation.	Many devices allow the user to download and install an application to use the unique technical characteristics of the device.

As for a comparison between an internet-enabled computer and mobile devices (a smartphone in particular) in terms of task performing, Figure 3-13 shows that the smartphone is better in performing telephone calls, indoor shopping, SMS, MMS, proximal searches and is even best in localisation, motion detection, media capture and

distribution. At the other end of the spectrum, personal computers are suitable for tasks such as processor-intensive statistical analysis and, while tasks such as word processing, spreadsheet analysis and presentation preparation are technically possible on a mobile device, it would be far easier to use a PC.



Figure 3-13 The Computer-Smartphone Capability Spectrum (Pitt et al., 2011)

Due to the outlined characteristics, Pitt et al. (2011) believe in, and put forward, the use of smartphones and their capabilities as integral parts of green information systems in order to make important contributions towards a sustainable world. However, in the context of this research, it is more significant to have an application that can put together all the smartphone capabilities so that the user will be able to capitalise their features at one venue. Otherwise, the user will still rely on the personal computer and use the smartphone as a tool (as a camera, voice recorder etc.), not as an embedded system.

3.7. MOBILE CHALLENGES

Despite recent progress in mobile device technology, cellular network bandwidths are still limited, weaker and less stable than their fixed-line counterparts (The World Wide Web Consortium (W3C), 2008). The result of this is longer and less predictable network latency and user wait time and, consequently, a worse user experience, especially for web sessions involving sequences of user actions and Internet requests/responses (Dong et al., 2010).

Therefore, with the forecasted massive increase in the consumption of mobile Internet services, it is interesting to understand how today's macro-cellular networks are positioned to accommodate this unparalleled growth in capacity. Grayson, et al. (2011) highlight that the capacity of a conventional cellular system can be evaluated by examining three key cellular characteristics as follows:

- **Spectrum:** The capacity of a mobile system depends on the amount of available radio frequency spectrum which is limited. It must be available in sufficient bandwidths to support higher-speed access while also providing good propagation characteristics which are required for providing wide-area coverage.
- **Spectral efficiency:** The efficiency by which the spectrum is used is another critical factor in determining the capacity of a mobile system. There is an upper boundary to the amount of information that can be transferred in a given bandwidth which is subject to background noise, termed the Shannon Limit. It is generally accepted that, as more advanced signal-processing techniques are applied to mobile communications systems, they are rapidly approaching such a theoretical limit.
- **Frequency reuse:** Because of its relative scarcity, mobile systems are required to reuse their allocated radio spectrum across a particular network of cell sites. Increasing the capacity by frequency reuse typically means dividing an existing cell into multiple smaller cells.

Grayson et al. further elaborate that the future mobile Internet requires networking technology that supports the following:

- Scalable adoption of small-cell technologies - for example, using unlicensed IEEE 802.11 technology or licensed cellular-based home base station solutions.

- A massive number of always-on devices, including scenarios where single subscribers have access to multiple devices.
- Ubiquitous access, including nomadic access from within buildings as well as wide-area mobile access for on-the-go consumption.
- Seamless access to a range of mobile services, including video, web access, peer-to-peer, Voice over IP (VoIP) and gaming services.

Beside the challenges on the infrastructure, browsing the web from mobile devices is still bound to the small form-factor of mobile devices which can discourage users from using mobile devices, instead of PCs, to perform web-related activities. The small form-factor of mobile devices makes them more challenging in terms of interaction. The miniaturised keypads and minimum arm-support makes it difficult to input text; the small screen makes it hard to click/tap at the right places or to read what is on the screen, and the simplicity of the user interface and the lack of mechanisms for easy copy/paste makes it difficult to move data from one application to another (Ayob et al., 2009, Guirguis and Hassan, 2010, Kao et al., 2009, Chen et al., 2010).

Because of these reasons, Rabin and McCathie-Nevile (2008) at The World Wide Web Consortium (W3C) have come out with the “Mobile Web Best Practices 1.0”; a basic guideline which specifies best practices for delivering Web content to mobile devices (Rabin and McCathieNevile, 2008). In addition, a few other authors such as Firtman (2010) and Myers et al. (2012) have provided some guidance on this matter as well. Table 3-2 provides a summary of what should be considered when developing a mobile web.

Table 3-2 Areas for Consideration When Developing a Mobile Web (Rabin and McCathieNevile, 2008, Firtman, 2010, Myers et al., 2012)

Area	Issues	Description
Connectivity	<ul style="list-style-type: none"> • Cost • Device provisioning • Network speed • Network latency • Network availability in remote areas • Service reliability 	<ul style="list-style-type: none"> • Keeping site entry point URLs short is recommended so that it is possible to reduce the chance of error and provide a more satisfactory user experience. • It is recommended that the page title be short but descriptive by using clear and simple language. • Mobile data transfer often costs time and money, therefore smaller sites with simple but consistent navigation and typing make users happier by costing less in time and money. • Smaller sites can become critical due to limited bandwidth. • The content of the web should be suitable and limited to what the user has requested. To satisfy this requirement, a website can be divided into several pages but with limited size portions. • Multiple external resources should be minimized.
Diversity Devices	<ul style="list-style-type: none"> • Numerous web browsers • Multiple versions of runtimes for Java or other languages 	<ul style="list-style-type: none"> • To better serve more mobile users, always keep mobile features relevant to the simplest device. In mobile, less is more!

Area	Issues	Description
Device Constraints	<ul style="list-style-type: none"> • Limited memory or processor • Small screen size • Multiple operating systems • Multi-tasking capabilities • Data cache sizes • Limited processing power 	<ul style="list-style-type: none"> • The appearance of the mobile web layout might be limited because the style sheets and font related styling (particularly on proprietary device web browsers) is not always available. • Mobile browsers often do not support “cookies”, scripting or plug-ins. So one has to be more careful when selecting the supported content. • Page rendering may take a noticeable time to complete due to quite limited processing power. In addition, such processing uses more power as does communication with the server. • Many devices have limited memory available for pages and images and exceeding their memory limitations results in incomplete display and can cause other problems. • With regards to graphics, large or high resolution images should be avoided except for critical information which would otherwise be lost. • In term of colours, it is important to ensure that foreground and background colour combinations provide sufficient contrast and that the information conveyed with colour is also available without colour. • Style sheets should stay small and scrolling should be limited to one direction vertically.

Area	Issues	Description
Input Devices	<ul style="list-style-type: none"> • Touch screens • Stylus • Mouse • Buttons • Rollers 	<ul style="list-style-type: none"> • The design of the web should consider the types of input from a user e.g. touchscreen, optical or mechanical joystick (ball, dpad) and keyboard to interact with the intended mobile content. • Keyboards and other input methods on mobile devices can be tedious to use, so it is recommended that the number of keystrokes must be kept at a minimum; however avoid free text entry where possible. Depending on the target devices, it is better to specify the inputs to a default text entry mode, language and/or input format. • Assistance to the user by providing pre-selected default values where possible is important. • As the scrolling has to be limited to one direction vertically, a logical order through links, form controls and objects would be necessary. • All form controls should be labelled appropriately and explicitly associate those labels with form controls. These labels must be positioned so they are laid out properly in relation to the form controls they refer to.

3.8. MOBILE WEB/APPLICATION FOR ENVIRONMENTAL SURVEILLANCE

A number of mobile application tools, whether on web or mobile operating system (Apple and Android) platforms, have been developed and commercialised. However, only a few of them relate to environmental surveillance and, therefore, a review has to be made in order to identify the relevant existing applications in this sector. The aims of the review are to identify the applications (web based/Apple/Android) that have the ability to help users conduct a walk-through environmental inspection on construction sites and/or capture the measurement of air and noise quality at a specific location as desired by the users.

The reviews was carried out within three months started on 26th April 2014, started with the reviews of the website of the United States Environmental Protection Agency (EPA) (<http://www.epa.gov/mygreenapps/>) on their database of Green Apps and the website of EHSfreeware on their free virtual library of Environmental, Health & Safety apps (<http://www.ehsfreeware.com/>) for the smartphone or other mobile device. The following keywords were used for the search on these websites: “Inspection, Environmental, Environmental Best Practices, Environmental Inspection, Air, Air Quality Monitoring, Noise and Noise Quality”. Early findings have shown that 8 air, 1 noise, 2 environmental best practices and 1 environmental inspection came forward from those categories. However, out of these, only 2 air, 1 noise, 2 environmental best practices and 1 environmental inspection were considered relevant mainly because the others focussed more on general purposes e.g. environmental status or Air Pollution Index (API) by countries or cities. And, it is important to note, that even for noise quality monitoring, the apps that were found are only an application to measure noise sound level by using the user’s phone’s microphone.

The number of applications relating to walk-through environmental inspections on construction sites and/or for capturing the measurement of air and noise quality on those two websites were found limited. Thus, it was decided to expand the search to the Google Play Store and Apple App Store. Again, more generic applications like iAir Quality-Global Air Quality by Yao Jingxian, APIMS-Malaysian Air Quality Index by Applique Weather and Air Quality in Europe by eMotion Tank Health and Fitness or applications to use the users’ phones’ microphones for noise measurements were

generally found. As a result, after a thorough review, two additional apps for noise quality monitoring, two apps for environmental best practice were found and, finally, seven apps were found for environmental inspection. Several applications that relate to the activities of walk-through environmental inspections and environmental monitoring (Air and Noise Quality) are reviewed in Table 3-3.

As can be seen in Table 3-3, a wide range of mobile tools for walk-through inspections and for air and noise quality monitoring exists but they are only intended to work separately by focusing on very specific tasks. Furthermore, they are not really customised for the use of construction environmental management except for the EnviroCheck by M.C. Wright & Associates Ltd. which is specifically designed to assist teams in meeting LEED® SS prerequisite 1 Construction Activity Pollution Prevention and covers all the criteria in the 2012 U.S. EPA Construction General Permit. However, this app is a stand-alone system design and is unable to integrate with other systems and this makes it suitable only for inspections or audit exercises. Other than EnviroCheck, many of applications are of a more generic application with some of them allowing the user to customise the inspection checklist. For example, Nimonik Audit by Nimonik Inc. where the system allows the users to build their own audit checklists, issue comparative reports of locations and audits, take notes, and record findings and conclusions. But again, this is just for a very specific task (audit and inspection) without any integration with other technologies or smart objects e.g. wireless sensors networks, weather stations, etc.

It is well understood in the literature that environmental inspection and environmental monitoring (measurement) should complement each other for the better management of environment (International Network for Environmental Compliance and Enforcement (INECE), 2009). Furthermore, as the nature of construction works and processes are fundamentally different compared to other industries like manufacturing, for example, there is a requirement for a dedicated application that addresses the environmental aspects and impacts of construction activities and which is suitable for the needs of the industry's players. In addition, such an application should not just collect, store and disseminate field data or information to offices or other important personnel but should also keep the users informed with real-time environmental monitoring data as well as other supplementary information (e.g. traffic and weather information) so that the users can make timely and well-informed decisions. Moreover, such a system's ability to send

a warning sign concerning areas of construction activities that require immediate corrective action, to perform real-time data updates and to retrieve precise up-to-date information from an internal database rapidly and efficiently would support environmental surveillance on sites and decision making by environmental professionals in difficult situations.

Table 3-3 Review of environmental inspection, audit and environmental monitoring (Air and Noise Quality) tools

Nos.	Name	Platform
Air (Measurement of Dust or PM₁₀)		
1	<p>AirCasting App by HabitatMap.</p> <p>AirCasting is an open source project for recording, mapping and sharing health and environmental data (Sound levels, fine particulate matter (PM_{2.5}), temperature, humidity, CO and NO₂) gas). Sound levels recorded by the users' phone microphone; however users have to buy additional Arduino-powered devices namely Arduino-powered AirBeam and AirCasting Air Monitor to measure other concentrations. Each AirCasting session lets the users capture real-world measurements, annotate the data for reporting, and share it via CrowdMap.</p>	Web/Apple/Android
2	<p>Air Visibility Monitoring by Robotic Embedded System Laboratory</p> <p>Air Visibility Monitoring uses an optical technique to measure air visibility (and hence an estimate of some kinds of air pollution) using cameras and other sensors available on smartphones. The users take pictures of the sky and tag it with location, orientation and time data, then send it to a backend server. Visibility is estimated by first calibrating these images radiometrically and then comparing the intensity with an established model of sky luminance.</p>	Android

Nos.	Name	Platform
Noise (Measurement of Sound Level dBA)		
1	<p>Environment Monitor App By Outsourcing Partner.</p> <p>This Android app measures sound intensity (dB scale with a digital display and LEDs in different colours).</p>	Android
2	<p>Sound Meter by Smart Tools</p> <p>The SPL (sound pressure level) meter app uses the built-in microphone to measure noise volume in decibels (dB), and shows a reference. However, the maximum values are limited by the hardware limitation due to the built-in microphone being aligned to the human voice (300-3400Hz, 40-60dB). For example, note the the maximum values for Moto Droid (100dB), Galaxy S3 (81dB), Galaxy Note (91dB) and Galaxy S2 (98dB). Therefore, a very loud sound (100+ dB) cannot be recognized.</p>	Apple/Android
3	<p>Measuring Center by SPL-Lab</p> <p>As the maximum values of sound pressure levels are limited by the hardware limitation of the smartphone,</p>	Apple/Android

Nos.	Name	Platform
	<p>SLPS-Lab has developed a simplified PC version of the Measuring Center for Android. It supports both wired Spl-Lab devices (USB BASS Meter, USB RTA Meter, etc.) and wireless devices, such as Wireless Bass Meter, so that the measurement can be higher than the limitation of the phone's built-in microphone.</p>	
Environmental Education		
1	<p>Environmental Educator By Environmental Educator LLC.</p> <p>This app will teach you how to protect the environment and why you should protect it. The Environmental Educator provides one topic a week on how to, and why we should, protect the environment, with the daily video segments being about 30-40 seconds.</p>	Web/Apple/Android
2	<p>Pollution By aMobileFuture.</p> <p>An iPhone app that provides users with information about the sources of pollution and the measured parameters in Europe.</p>	Apple
3.	<p>FE Environmental Engineering by Faadooengineers.com</p> <p>This application is for all students in environmental engineering. It covers 89 topics of environmental engineering and these topics are divided into 7 units. Each topic is like a detailed flash card that comes complete with diagrams, equations and other form of graphical representations along with simple text</p>	Android

Nos.	Name	Platform
	explaining the concept in detail.	
4	<p>Environmental Engineering by Rikpart</p> <p>This application contains every short definition that relates to Environmental Engineering.</p>	Android
5	<p>Career Paths – Environmental Engineering by Express Publishing</p> <p>Career Paths: Environmental Engineering provides a new educational resource by incorporating career-specific vocabulary and context. This app addresses topics covering aspects of environmental engineering such as air pollutants, water treatment, ecosystems, irrigation and career options. It is suitable for environmental engineering professionals who want to improve their English communication in a work environment as it has the modules that offer step-by-step instruction that immerses students in the four key language components: reading, listening, speaking and writing.</p>	Apple
6	<p>Dictionary of Environmental Engineering by Acolada GmbH</p> <p>This app comes with about 35,000 keywords. This dictionary covers the following aspects of environmental</p>	Apple

Nos.	Name	Platform
	<p>engineering tagged with the corresponding labels: a machine-readable text corpus to identify the most common word forms and specialist phraseology. This methodological approach was supplemented by a traditional analysis of reference books, trade journals and sources of information on the internet.</p>	
Inspection		
1	<p>Nimonik Audit By Nimonik Inc.</p> <p>Nimonik Audit helps users to conduct inspections on Safety, Quality and Environment at their facilities. This apps allows the users to build their own audit checklists; to schedule audits and inspections; to issue comparative reports of locations and audits; to take notes, record findings and conclusions and to issue corrective actions to colleagues or clients etc.</p>	Apple
2	<p>YellowJacket by Mace Ltd.</p> <p>This application is made available to YellowJacket customers. With a registered YellowJacket account, a user would be able to use this application to perform observations, inspections or audits when they are on site or in a building. The users can record the observation by answering the inspection and audit questions,</p>	Apple

Nos.	Name	Platform
	<p>can upload pictures and can specify the exact location of an observation or action by referring to the floor plans for each building or site which were pre-loaded onto the YJ app. This app can be used underground or in an area with no signal. Any changes made are automatically synched once your device is connected to the internet.</p>	
3	<p>Formyula by Environmental Reports Inc.</p> <p>Formyula is an add-on to the Environmental Reports' subscription based service. This app has the ability to collect, store, organize and manage the field data. It allows the users to record GPS location, take photos, and create audio notes while on the job. The report can also be delivered to the office or partners in real time.</p>	Apple
4	<p>iForm EHS by Zerion Software</p> <p>iForm EHS provides detailed iOS (iPad, iPhone and iPod touch) EHS Audit/Inspection forms and programmes' assessment tools to help EHS professionals in inspections and in conducting audits and incident and programme evaluations. Therefore, the EHS professionals can gather data, on or off the network, take photos, assign items for follow-up, share reports via email, or create an audit scorecard to show status and track progress.</p>	Apple
5	<p>EnviroCheck by M.C. Wright & Associates Ltd.</p> <p>EnviroCheck is specifically designed to assist teams in meeting LEED© SS prerequisite 1 Construction</p>	Apple

Nos.	Name	Platform
	<p>Activity Pollution Prevention and covers all the criteria in the 2012 U.S. EPA Construction General Permit. By using the standardised checklist, the users have to answer inspection and audit questions by selecting "yes", "no" or not applicable ("N/A") and by taking photos using the mobile devices while performing the inspection. The users then can submit their report wirelessly (via wifi or the cellular phone network) to the web-based database and it will appear in the client's inbox as a PDF report with full colour photos.</p>	
6	<p>Easy to Inspect by Easy to Inspect</p> <p>Easy to Inspect allows the users to create and manage custom made checklists. The users then are able to use the checklist for conducting an inspections, checks or audits with their smartphone or tablet and can send the results to the Easy to Inspect web-based checklist manager.</p>	Android
7	<p>Inspection, Checklist, Audit by IMEC Technologies</p> <p>Inspection, Checklist, Audit enables the user to perform the inspection via a smart phone, tablet or mobile computer. Checklists can capture photographs, GPS coordinates, numbers, free text, signatures and barcodes. Once completed, the reports can be printed or can be emailed to the appropriate person. Audit reports include all photographs, signatures gathered during the inspection or audit together with the GPS coordinates, as a google map, of where the audit was performed.</p>	Android
8	<p>Inspection Form Manager (IFM) by Intetics Co.</p> <p>This application provides a custom-made checklist that the user is able to fill on their mobile devices. They</p>	Android

Nos.	Name	Platform
	can also take photographs by using the phone's camera during the inspection, can track GPS location and add comments.	

3.9. SUMMARY

The literature review undertaken for this study has shown that earlier versions of Environmental Information Systems (EIS) such as INFOTERRA, GRID and others have improved the dissemination of information but as they were mainly designed for the desktop user and rely on traditional methods for the environmental quality data, these systems were immobile and not capable of delivering real-time data. As a result, these systems were not able to allow users to get immediate feedback from the system; such swift feedback is a crucial element that is required by an environmental management team in making fast decisions. In addition, a disadvantage of such systems was the possibility of increased typographical errors, causing inconsistencies in information as well as the potential loss of information in some instances.

On the other hand, mobile environmental information systems (MEISs) through the mobile web offer more mobility for both systems and users; they are able to integrate with functional mobile devices and sensory technologies, and accommodate the need for real-time data streaming and fast reporting. Any system, however, should be designed taking into account the restricting capabilities of mobile devices such as limited network bandwidth, smaller processor memory, simplicity of user interface, miniaturised keypads and small screens (Ayob et al., 2009, Guirguis and Hassan, 2010, Kao et al., 2009, Chen et al., 2010).

Technology by itself would not guarantee success if the system were unable to meet the needs of the user. Therefore, it is important to understand the relationship and interaction between the user (human) and the application (computer) before developing any computer application. The success of the application depends on the appropriate research philosophy, methodology and techniques. These subjects will be the focus of the next chapter.

CHAPTER 4. RESEARCH METHODOLOGY

4.1. INTRODUCTION

The findings from the literature review, which were discussed in Chapters 2 and 3, formed the basis for this research. The review shows that the communication and delivery of environmental information could be improved through the use of mobile applications and sensory technologies for both physical surveillance and technological based surveillance. The review suggests that environmental professionals could carry mobile devices with wireless communication connection to field locations for their data collection and validation tasks. They can easily retrieve data and information from the web servers and/or perform real-time data updates, exchange data between those servers and receive a warning sign alert from the environmental sensor (if any) on their mobile devices, simultaneously.

4.2. THE CONCEPT OF RESEARCH AND RESEARCH METHODOLOGY

According to Kuhn (1996), research is generally defined as a task that leads to the understanding of a phenomenon. The phenomenon is generally a collection of behaviours by an entity/small number of entities deemed important by the researcher or by a research community. In most Western research communities, ‘understanding’ refers to the knowledge that helps them to predict the behaviour of some aspect of the phenomenon, whilst a set of activities deemed appropriate by the research community in the production of understanding (knowledge) is known as a research method or technique (Vaishnavi and Kuechler Jr, 2007).

In a later definition, Saunders et al. (2009) define research as the systematic collection and interpretation of information with a clear purpose, to find things out. Thus, in general, the emphasis of those two definitions lies on the research concern of what is being studied (discovery of information and understanding) and how to study the subject in detail (method of study).

Research can be conducted using various approaches. Saunders et al. (2009) for example, have introduced the methodology of an 'onion' research model. In this model, several layers are identified with the research problem lying in the centre (Figure 4-1). These layers need to be explored prior to any attempt to address the research problem.

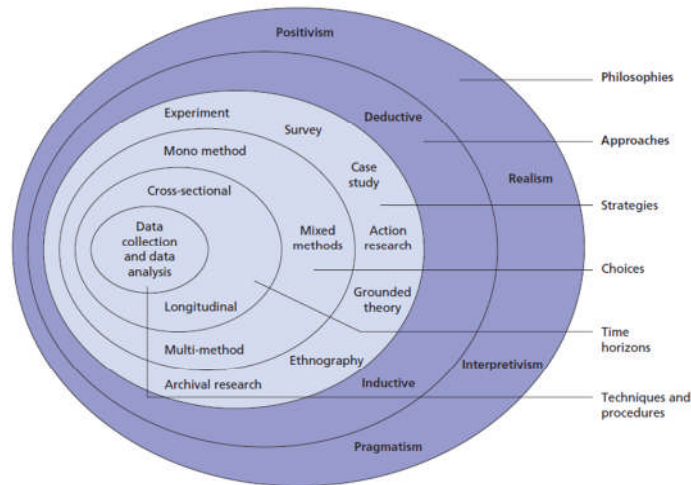


Figure 4-1 The Research 'Onion'

However, Kagioglou et al. (2000) have developed a nested research methodology which provides the researcher with an integration of the research approach and techniques that benefit from an epistemological level direction and cohesion. Figure 4-2 shows a diagram representing the nested research methodology. The outer ring of the nested research methodology represents the unifying research philosophical paradigms, or worldview, which guides and energizes the inner research approaches and research techniques. The research approaches consist of the dominant theory-generation and testing methods. The research techniques comprise data collection tools.

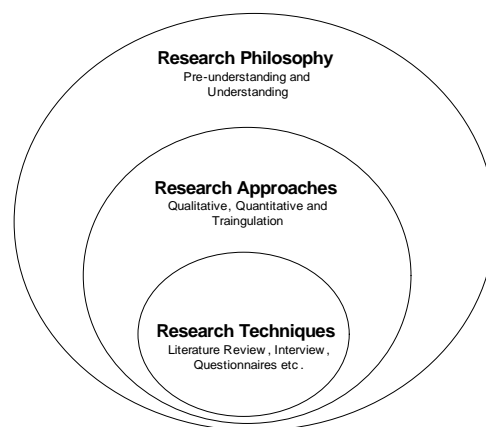


Figure 4-2 The Nested Research Methodology (adopted from Kagioglou et al., 2000)

Last but not least, Takeda et al. (1990) introduced a general design cycle of software. Vaishnavi and Kuechler (2004) extended this analysis to explicate the knowledge generated in a design effort and apply the cycle specifically to information systems' design science research leading to the general design cycle framework illustrated in Figure 4-3 which has become a well-known research methodology for Information Systems (IS) research particularly for design science research. In this model, all research starts with the Awareness of a Problem. An awareness of an interesting problem can come from multiple sources: new developments in the industry or in a reference discipline. Intimately connected with the Awareness of a Problem is the Suggestion phase. Suggestions are abductively drawn from the existing knowledge or theory base for the problem area. This will followed by the development of an artefact according to the suggested solution. The artefact then will be partially or fully implemented and evaluated according to the functional specification implicit or explicit in the suggestion. Development, Evaluation, and further Suggestions are often iteratively performed in the course of the research (design) effort (Vaishnavi and Kuechler, 2007a). The Circumscription arrow indicates the iteration; the flow from partial completion of the cycle back to the Awareness of Problem. The Conclusion indicates termination of a specific design project.

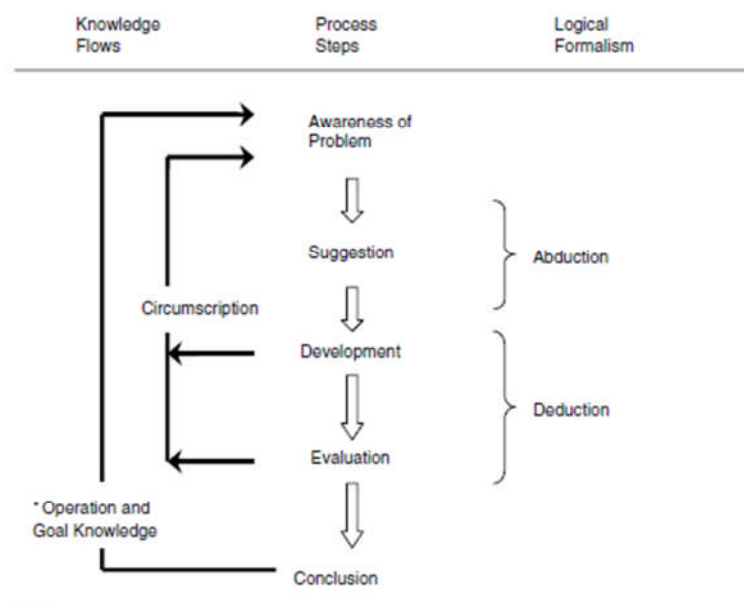


Figure 4-3 General Design Cycle Framework (GDC)

4.3. RESEARCH PHILOSOPHICAL PARADIGMS OR WORLDVIEW

Research philosophical paradigms or worldview is a way of examining social phenomena from which a particular understanding can be gained and explanations attempted (Saunders et al., 2009). Two of the most central concepts of the philosophy of science are ontology and epistemology.

Ontology, also known as ‘first philosophy’ (Masadeh, 2012), is the science of being which encompasses essential questions about reality and existence and their function (Masadeh, 2012, Kamil, 2002). It poses questions about ‘what is’- that is, questions involving the nature and content of existence, including social and political reality, and the kinds of interactions that shape that reality (Blaikie, 1993). Whereas Epistemology, the science of knowledge, is concerned with how a researcher comes to know about the world (Kamil, 2002) and probes the nature and limits of human knowledge (Masadeh, 2012, Guisepe, 2007). The term epistemology denotes "the nature of human knowledge and understanding that can possibly be acquired through different types of inquiry and alternative methods of investigation" (Hirschheim et al., 1995).

Epistemological approaches vary widely and have split into different directions over the past half-century in the work of philosophical schools like positivism, critical paradigm, constructivism, pragmatism, etc. According to Cater-Steel and Al-Hakim (2008), the positivistic (or conventional) and constructivist (or interpretive) paradigms are the diverging paradigms commonly adhered to in IS research.

The dominant approach to information technology studies has been based on a positivistic experimental ideal of research (Kaplan and Duchon, 1988, Chen and Hirschheim, 2004). Positivism, which emerged from the work of 19th century French philosopher Auguste Comte, defines knowledge in terms of empirically verifiable observation (Masadeh, 2012). For positivism, knowledge is limited to only those phenomena that can be observed, measured, recorded, etc (Blaikie, 1993; Hussey and Hussey, 1997, cited in (Masadeh, 2012) and the world is considered an external object of investigation, separate from the subjective experiences of the researcher (Masadeh, 2012). Any researcher will probably adopt the philosophical stance of the natural scientist (Saunders et al., 2009, Bryman, 2008) whose goal is to gain knowledge of an external reality (Masadeh, 2012). Positivism is fuelled by a desire to represent a closure on reality; it frequently involves “an unreflexive use of methods (e.g., experiments,

hypothesis testing, quantification) assumed to be successful in the natural sciences and readily transferable to the domain of the social sciences” (Knights, 1992, cited in (Kanellis and Papadopoulos, 2009). However, as IS are sociotechnical systems, what gives birth to information are the concerns of the perceiver, that is, the user of the information system. Such a definition of information emphasises the social dimension of the system that is supposed to provide it; it also prohibits us from forgetting the distinctive nature of the social dimension in contrast to natural phenomena. However, positivism denies this distinction.

Interpretivism is a term that usually denotes an alternative to the positivist orthodoxy. Although not the dominant paradigm, interpretive perspectives have been used in a variety of ways in information systems research (Kaplan and Duchon, 1988). Interpreting information technology in terms of social action and meanings is becoming more popular as evidence grows that information systems development and use is a social as well as technical process that includes problems relating to social, organizational and conceptual aspects of the system (Kaplan and Duchon, 1988). The Interpretist view is that the subject matter of the social sciences (people and their institutions) is fundamentally different from that of the natural sciences (Bryman, 2008, Saunders et al., 2009). This emphasises the difference between conducting research among people rather than among objects such as trucks and computers (Saunders et al., 2009). The study of the social world, therefore, requires a different logic of research procedure (Bryman, 2008) where the researcher is required to understand differences between humans in their roles as social actors and to interpret their role in accordance with the researcher’s own set of meanings (Saunders et al., 2009). In IS research, interpretive research can help researchers understand human thought and action in social and organizational contexts; it has the potential to produce deep insights into information systems’ phenomena including the management of information systems and information systems development (Klein and Myers, 1999).

In addition to the positivistic (or conventional) and constructivist (or interpretive), Design-Science Research (DSR) has emerged as a paradigm for performing research in Information Systems (IS) over the last few years (Kanellis and Papadopoulos, 2009). This is an alternative to the natural/behavioural science paradigm. March and Smith (1995), Gregor and Jones (2007) and Hevner et al. (2010) note that the design science paradigm aims to widen the boundaries of human and organizational capabilities to

solve identified problems by developing new and innovative artefacts, comprising constructs (a set of vocabulary and symbols), models (abstractions and representations), methods (algorithms or practices), and instantiations (implemented and prototyped systems). The DSR researcher with the guidance of his/her own interests, values, and assumptions engages in creating new realities that change the state-of-the-world. This occurs through the introduction of new and novel artefacts which are not natural, neutral, or given (Orlikowski and Baroudi, 1990). This contrasts with the typical view of positivistic ontology where a sociotechnical system is taken for granted and is the typical unit of analysis (Vaishnavi and Kuechler, 2007a). Nevertheless, DSR has contrasting interpretive ontology as well in that DSR researchers may possess multiple world-states which are not embedded into different and multiple realities, as interpretivism advocates. Reality for DSR is stable and places constraints on the multiplicity of world-states (Gregg et al., 2001). For instance, the abductive phase of DSR (Figure 4-3) requires the suggestion of an artefact with intended problem solving; this can be achieved by adhering to a fixed grounding reality (Vaishnavi and Kuechler, 2007a).

Table 4-1 Philosophical Assumptions of Three Research Perspectives (Vaishnavi and Kuechler, 2007b)

Research Philosophy			
<i>Basic Belief</i>	<i>Positivist</i>	<i>Interpretivist</i>	<i>Design Science Research</i>
Ontology	A single reality Knowable Probabilistic	Multiple realities, socially constructed	Multiple, contextually situated in alternative world-states Socio-technologically enabled
Epistemology	Objective; dispassionate, detached observer of truth	Subjective (i.e., values and knowledge emerge from the researcher- participant	Knowing through making: objectively constrained construction within a context Iterative circumscription

Research Philosophy			
<i>Basic Belief</i>	<i>Positivist</i>	<i>Interpretivist</i>	<i>Design Science Research</i>
		interaction)	reveals meaning
Methodology	Observation; quantitative, statistical	Participation; qualitative. Hermeneutical, dialectical	Developmental Measure artifactual impacts on the composite system
Axiology: what is value	Truth: universal and beautiful; prediction	Understanding: situation and description	Control; creation; progress (i.e., improvement); understanding

4.4. RESEARCH APPROACHES AND STRATEGIES IN INFORMATION SYSTEM RESEARCH

Philosophical paradigms for research contain important assumptions about the way in which a researcher views the world. The decisions from these broad assumptions should direct the plans and the procedures which will later be adapted as the research approach for any given research project or programme (Creswell, 2009). These research approaches should provide a framework for the research strategy and the methods for the collection and analysis of data. Therefore, early decisions are crucial as the approach should be based on the nature of the research problem or issue being addressed in addition to the researcher's personal experiences and the audience for the study (Creswell, 2009).

There are three types of research approach which are quantitative, qualitative or a combination of both methods called triangulation or the mixed research method (Fellows and Liu, 2003; Neuman, 2006). Many research projects use more than one

approach in order to capitalise on the strengths of each approach and to compensate for any weaknesses encountered (Love et al., 2002). Thus, the triangulation or the mixed approach may be able to enhance the quality of a study especially in built environment research (Amaratunga et al., 2002).

4.5. RESEARCH TECHNIQUES IN INFORMATION SYSTEMS RESEARCH

Just as there are various philosophical perspectives and research approaches which can inform Information Systems (IS) research, so there are various research methods. A research method is a strategy of inquiry which moves from the underlying philosophical assumptions to a framework for the collection and analysis of data (Bryman, 2008, Myers and Avison, 1997). The choice of research method influences the way in which a researcher collects data. Specific research methods also imply different skills, assumptions and research practices. As no research strategy is inherently superior or inferior to any other, the choice of study design should be guided by the research question(s) and objectives, the extent of existing knowledge, the amount of available time and other resources, as well as the research's philosophical underpinnings (Saunders et al., 2009). In the context of mobile HCI research methods, Kjeldskov and Graham (2003) have outlined the research methods that apply within the field of mobile human-computer interaction. Therefore, for the purpose of this study, the list of applicable research methods, as outlined by Kjeldskov and Graham (2003), will be used as a guide and various research works (Neuman, 2007, Kjeldskov and Graham, 2003, Myers and Avison, 1997) will be cited for further discussion of definitions. The research methods that will be discussed are listed below:

1. Case studies;
2. Field studies;
3. Action research;
4. Laboratory experiments;
5. Survey research;
6. Applied research, and
7. Normative writings.

4.5.1. CASE STUDIES

Yin (2003) defines case study as an empirical enquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 2003, Robson, 2002, Saunders et al., 2009). It is the most common qualitative method used in information systems and it is well-suited to IS research, since the interest in the IS discipline has shifted to organizational rather than technical issues (Myers and Avison, 1997). The case study approach seeks to understand the problem being investigated. The case study strategy also has considerable ability to generate answers to the question ‘why?’ as well as to the ‘what?’ and ‘how?’ questions (Saunders et al., 2009).

Case studies are often intensive empirical studies of small size entities such as individuals, social groups, organizations and institutions, systems or tools with the researcher distinct from the phenomena being studied (Kjeldskov and Graham, 2003, Robson, 2002). Case study research may be carried out as a single case or multiple cases. A single case may be selected because it provides an opportunity for observation and analysis of a phenomenon that few have considered before, or it represents a critical case or, alternatively, an extreme or unique case, whereas the rationale for using multiple cases focuses upon the need to establish whether the findings of the first case occur in other cases and, as a consequence, these findings need to be generalised (Saunders et al., 2009). For this reason Yin (2003) argues that a strong justification is needed for a single case study and, because of that, multiple case studies may be preferable to a single case study.

When conducting case studies, data is typically collected from a small number of organisations through various techniques which are likely to be used in combination. They may include, for example, interviews, observation, documentary analysis and questionnaires (Gable, 1994). The data collected is grounded in natural settings, typically very rich and sometimes contradictory or inconsistent, thus often resulting in complicated analysis. It is important to note that case studies are very time demanding and generalizing findings can be difficult (Kjeldskov and Graham, 2003). In the context of mobile HCI, case studies could be used to provide rich data explaining phenomena involving mobility or the use of mobile devices in context (Kjeldskov and Graham, 2003).

4.5.2. FIELD STUDIES

Generally, field studies are characterized by taking place in the real world as opposed to in a laboratory setting. Field studies cover a range of qualitative and quantitative approaches from ethnographic studies of phenomena in their social and cultural context inspired by the discipline of social and cultural anthropology to field experiments in which a number of independent variables are manipulated (Kjeldskov and Graham, 2003).

Ethnographic field studies are characterized by researchers spending significant amounts of time in the field and, to some extent, immersing themselves into the environment they study. Typically, data is gathered through observations and/or interviews and the phenomena studied are placed in a social and cultural context. Ethnography may be very appropriate if the research wishes to gain insights about a particular context and to better understand and interpret it from the perspective(s) of those involved (Saunders et al., 2009). However, the major disadvantages of ethnographic field studies is that it is very time consuming and takes place over an extended time period as the researcher needs to immerse herself or himself in the social world being researched as completely as possible (Saunders et al., 2009).

While ethnographic field studies are non-experimental, field experiments are characterized by the manipulation of a number of independent variables to observe their influence on dependant variables in a natural setting. Field experiments are conducted in dynamic social, industrial, economic and political arenas, not in the laboratory environment (Fathi, 2009). The major advantages of field experiments are increased control in comparison to ethnographic field studies and the fact they support studying complex situated interactions and processes whereas the disadvantages include limited control of experiments and the fact they can be a more complicated and more time consuming data collection compared to, for example, experiments in laboratory settings (Kallio and Kaikkonen, 2005). In relation to mobile HCI research, field studies can be applied for either informing the design for, or the understanding of, mobility by ethnographic studies of current practice or for evaluating design or theory by conducting experiments in realistic use settings (Duh et al., 2006).

4.5.3. ACTION RESEARCH

There are numerous definitions of action research. However, one of the most widely cited is that of Rapoport's who defines action research in the following way:

Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework (Rapoport, 1970, p. 499).

While conducting action research, the researcher participates within the activity or phenomenon being studied while at the same time evaluating the results. According to Saunders et al. (2009), action research is particularly useful for 'how' questions and puts explicit focus on action, in particular on promoting change within the organisation. Therefore, it differs from the other research strategies because of its strength in focusing on change. The advantage of action research is the very close relationship between researchers and the phenomena of interest. This facilitates first-hand insight, limits researcher influence on the subjects being studied and supports a successful way of applying theory to practice and evaluating its outcome. However, action research is very time consuming and, since the researcher takes part in the phenomena studied while remaining objective, can be difficult. Also, when participating within an activity or phenomenon, considerations can emerge concerning, for example, if it is ethically acceptable for a researcher to conceal knowledge of particular approaches having better effects than others. Finally, the outcome of this type of research can be difficult to generalize.

In relation to mobile HCI research, action research could be used for extending field or case studies by researchers, participating actively in real world activities involving mobility, introducing different solutions or theories "on-the-fly" as well as evaluating their effects and/or validity (Kjeldskov and Graham, 2003).

4.5.4. LABORATORY EXPERIMENTS

In contrast to field studies, laboratory studies are characterized by taking place anywhere (laboratories, office, simulator, etc.) provided it is in a controlled environment created for the purpose of research. The purpose of an experiment is to study causal links, whether a change in one independent variable produces a change in another dependent variable. The data may come from quantitative methods (e.g. cognitive walkthrough method) or quantitative methods (e.g. heuristic evaluation or think-aloud protocols during the conduct of experimental tasks) (Kjeldskov and Graham, 2003).

The major advantages of laboratory studies is that they provide an opportunity to focus on specific phenomena of interest and a large degree of experimental control in terms of the manipulation of variables before and during the experiment (through, for example, the assignment of test subjects and exposure to different treatment variables). Also, laboratory experiments are typically highly replicable and facilitate good data collection. Disadvantages include limited relationships to the real world and an unknown level in the generalisability of the results outside laboratory settings.

In mobile HCI research, laboratory experiments are suitable for evaluating design ideas, specific products or theories about design, and user interaction in controlled environments with little or no interference from the real world.

4.5.5. SURVEY RESEARCH

Surveys generally inform research by delivering information from a recognised sample of people compiled within their individual environment through different systematic approaches. Basically, data are gathered via questionnaire surveys without researcher interference and are analysed quantitatively by using descriptive and inferential statistics (Saunders et al., 2009). The questionnaire, however, is not the main data collection technique that is part of the survey strategy. Structured observation (of the type normally involved in organisation and methods' (O&M) research) and structured interviews (when standardised questions are asked) also belong to this strategy (Saunders et al., 2009).

The essential benefits of surveys are that they enable a large amount of data to be collected with very minimal effort, assisting in the extensive generalization of the

outputs. Furthermore, a high level of control with regards to the sample subjects enables the minimization of potential bias, hence improving validity. In spite of this, surveys have problems by delivering only snapshots of the studied phenomena and depend highly on the subjective views of the respondents. In mobile HCI research, surveys may, for instance, enable generalisable information to be obtained regarding user needs and requirements in order to discover a phenomenon, build theory or develop systems. Additionally, surveys could be utilized for acquiring data regarding users' experience of specific products or designs for evaluation requirements.

4.5.6. APPLIED RESEARCH

As outlined by Kjeldskov and Graham (2003), applied research establishes on a trial and error based on the researcher's capabilities of judgment from intuition, experience, deduction and induction. Generally, the expected goal or output of the research process is known, with regards to requirements, at a certain level of abstraction; however methods or techniques for achieving this output are not clear, therefore, are requested through utilizing potentially relevant research. The benefits of applied research are that it is very goal-focused and (basically) leads to a number of products being produced that can be evaluated against the main goals. The main disadvantages of applied research are that the main solutions could be very minimal and not generalisable and that suitable solutions for obtaining the desired output may not be presented at all. In mobile HCI research, applied research is appropriate when considering the design and implementation of systems, interfaces and techniques which fulfil certain requirements for performance, user interaction, user satisfaction, etc.

4.5.7. NORMATIVE WRITINGS

Kjeldskov and Graham (2003) note that the category of normative writings comprises the concept 'development writings' including presentation of "truth" and "application descriptions" with a purpose of providing the "non-research" writings regarding phenomena of interest in the classification of research methods. The concept of development writings arranges ideas with the intention to assist and identify directions for future research. On the other hand, the "truth" category produces ideas and fundamentals, as well as recommendations, which appear to be intuitively right but are

not influenced by theory or research. Meanwhile, the application descriptions are described as “narratives written by practitioners”. It explains subjective ideas on a scenario and the items that were effective for them within that certain situation.

The main benefit of normative writings is that they need minimal action to deliver as opposed to producing complex theoretical concepts. The weaknesses of normative writings include minimal theoretical and methodological reflection and minimal generalisability. In mobile HCI, normative writings explaining designs and processes that proved helpful or which did not prove to be effective could be ideal for encouraging future research or design.

4.6. THE DEVELOPMENT OF THE PROTOTYPE MOBILE WEB

The word prototype generally means “a first or primitive form” and derives from the Greek word *prototypos* which is a combination of the word *proto* “first” and *typos* “impression, mold, pattern” (Harper, 2001). Definitions of prototype and prototyping vary of course, not the least because the label is used differently according to different disciplines: in engineering the word ‘prototype’ refers the first instance of a nearly final product (before it makes its way into serial production), while in design thinking the word ‘prototype’ refers to a rough ‘mock-up’ - a 3-dimensional sketch model which may be simply built from found materials (Müller and Thoring, 2011).

In IT/IS research, "prototypes" are representations of a design varying from rough sketches to very precise clay models to (partly) running systems which "looks like," "behaves like," and "works like" the real thing (Buchenau and Suri, 2000). They serve as materials to reflect and inform both the design process and design decisions for future artefacts (Hennipman et al., 2008).

There are two prototypes which are commonly recognized in the literature: low fidelity and high fidelity. A low-fidelity prototype uses a medium which is unlike the final medium, e.g. paper, cardboard (examples are sketches of screens, task sequences, ‘Post-it’ notes, storyboards, ‘Wizard-of-Oz’) whereas high-fidelity prototypes use a material that would be expected to be in the final product (Bailey et al., 2008, Müller and Thoring, 2011, Sharp et al., 2011). Rudd et al. (1996) describe the advantages and disadvantages in conducting low-fidelity and high-fidelity prototyping efforts which are

often referred to by the human computer interaction (HCI) community, see for example Sharp et al. (2011) and Engelberg and Seffah (2002). Table 4-2 summarises the characteristics of low-fidelity and high-fidelity prototyping.

Table 4-2 Low- and High-Fidelity Prototyping (Sharp et al., 2011, Rudd et al., 1996, Engelberg and Seffah, 2002)

Types of Prototype	Appearance	Optimal Uses	Advantages	Disadvantages
Low-fidelity Prototyping	Rough sketch; Highly schematic and approximate. Little or no Interactive functionality.	Early design: Conceptualizing and envisioning the application.	Lower development cost; useful Communication vehicle; proof of concept; evaluates multiple design concepts; useful for identifying market requirements.	Limited usefulness After requirements established; limitations in usability testing; limited error checking; poor detailed specification to code; facilitator-driven; navigational and flow limitations.
High-fidelity prototyping	Lifelike simulation of the final product; refined graphic	Marketing tool; training tool; simulation of advanced or highly	High degree of functionality; fully interactive; defines look	Expensive to develop; time consuming to build; inefficient for a

Types of Prototype	Appearance	Optimal Uses	Advantages	Disadvantages
	design. Highly functional, but the back end might be simulated rather than real.	interactive techniques.	and feel of final product; serves as a living specification; user-driven; clearly defines the navigational scheme; used for exploration and testing; marketing and sales tool.	proof-of-concept design; not effective for requirements' gathering.

It is important to recap that the overall aim of this research is to investigate the potential for a mobile environmental information system (MEIS) for environmental surveillance on Malaysian construction sites. But to advance this, of course, a prototype MEIS (an artefact in Design Science Research) must be developed and, subsequently, be implemented and evaluated for environmental surveillance on construction sites.

However, the success of the mobile web depends on the effective interaction between the user and the system. Therefore, it is important to conduct this research in a way which is related to the human-computer interaction (HCI) research discipline. The field of HCI addresses multi-disciplinary research approaches which draws on tools, techniques and paradigms from a variety of disciplines in both science and design (Kjeldskov and Graham, 2003). This is discussed further in the following section.

4.6.1. HUMAN-COMPUTER INTERACTION (HCI)

According to Ghaoui (2006), the ACM Special Interest Group on Computer-Human Interaction Curriculum Development and most of HCI literature define human computer interaction (HCI) as per the definition below.

Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use in a social context, and with the study of major phenomena surrounding them.

Many computer users today would argue that computer makers still do not pay enough attention to making their products “usable”, thus HCI has a vital role to play in providing solutions. Various design methodologies that are based on a model of how users, designers and technical systems interact has emerged. This attempt to address the issues of design, usability and interaction which are recognised as the core issues in HCI.

HCI is undoubtedly a multi-disciplinary subject (Fathi, 2009, Ghaoui, 2006) which draws on disciplines such as psychology, cognitive science, ergonomics, sociology, engineering, business, graphic design, technical writing and, most importantly, computer science and system design/software engineering. Two of the most influential sources are from design and science. Scientific research is generally carried out using empirical studies but, in the design disciplines, research is more often based on the development of prototype products, their evaluation and their refinement (Fathi, 2009). The integration of these two approaches, however, is achievable through the framework by Mackay and Fayard (1997) as shown in Figure 4-4.

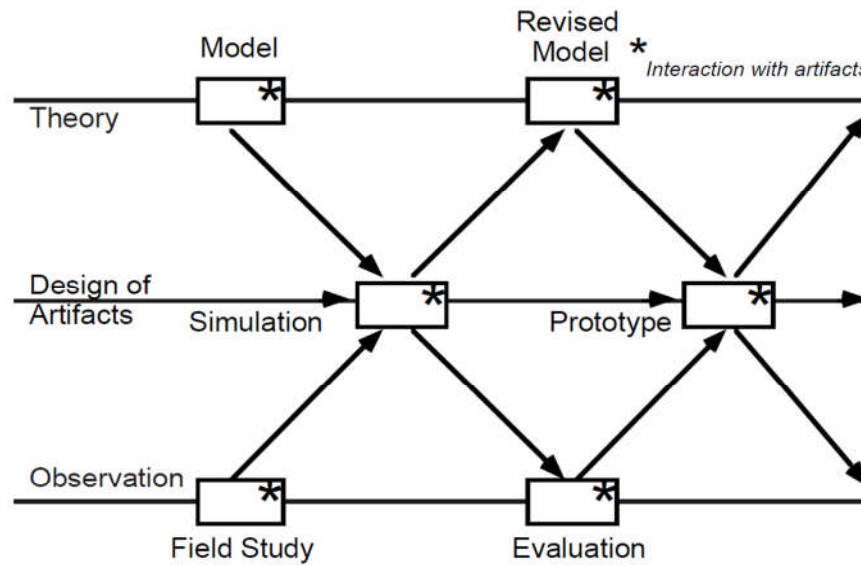


Figure 4-4 Integration of Science and Design (adopted from Mackay and Fayard, 1997)

Figure 4-4 illustrates how both design and scientific models can be integrated for the range of activity found in HCI. At the theoretical level, HCI can create and revise interaction models based upon the observations of users interacting with artefacts (Mackay and Fayard, 1997). At the empirical and real world level, HCI can observe how people interact with various technologies and develop models of use. In both cases, HCI can draw from theory and observation to initiate new artefacts, ranging from early simulations to working prototypes to products. By triangulating across the scientific and design disciplines that compose HCI, the validity and value of the research results can be increased. Before developing a prototype system, it is also important to have a brief review of the information system design philosophy (user centred design).

4.6.2. USER-CENTRED DESIGN (UCD)

'User-centred design' (UCD) represents the techniques, processes, methods and procedures throughout a product lifecycle for designing usable products and systems, but, equally as important, it is the philosophy that places the user at the centre of the process (Abrams et al., 2004, Rubin and Chisnell, 2008b, Baxter and Courage, 2005). Through this approach, users, designers and technical practitioners work together to define the needs, wants and limitations of users to create a system taking into account

these elements. For example, some types of UCD consult users about their needs and involve them during requirements gathering and usability testing.

On the other hand, there are UCD methods in which users have a deep impact on the design by being involved as partners with designers throughout the design process. ISO 13407 (1999) outlines four user-centred design activities that need to start at the earliest stages of a project. These are:

- Requirements gathering - understanding and specifying the context of use;
- Requirements specification - specifying the user and organisational requirements;
- Design - producing designs and prototypes, and
- Evaluation - carrying out a user-based assessment of the prototype at the project site.

In addition, Rogers et al. (2011) suggest various ways to involve users in the design and development of a product/artefact as shown in Table 4-3.

Table 4-3 Involvement of users in the design and development of a product/artefact (Rogers et al., 2011)

Techniques	Purpose	Stage of the Design Cycle
Background interviews and questionnaires	Collecting data relating to the needs and expectations of users; evaluation of design alternatives, prototypes and the final artefact	At the beginning of the design project
Sequence of work interviews and questionnaires	Collecting data relating to the sequence of work to be performed with the artefact	Early in the design cycle
Focus groups	Include a wide range of stakeholders to discuss	Early in the design cycle

Techniques	Purpose	Stage of the Design Cycle
	issues and requirements	
On-site observation	Collecting information concerning the environment in which the artefact will be used	Early in the design cycle
Role playing, walkthroughs and simulations	Evaluation of alternative designs and gaining additional information about user needs and expectations; prototype	Early and mid-point in the design cycle

Baxter and Courage (2005) and Rubin and Chisnell (2008b) emphasise that there are three basic principles of user-centred design. The first principle focuses on the systematic and structured collection of users' requirements. To maximise the usability of a product, the user should be involved from the product's inception i.e. user requirements' gathering. Engaging the users helps the designer to manage the users' expectations and levels of satisfaction with the product while developing a sense of ownership among the users for the product. Moreover, this collaborative process generates more creative design solutions to problems and, most importantly, the produced products require less redesign at the final stages of the lifecycle (e.g., after a usability test) and integrate into the environment more quickly. This approach, however, may require the involvement of additional design team members (e.g. ethnographers, usability experts) and a wide range of stakeholders. In some cases, the product may be too specific for more general use and may not be readily transferable to other clients, thus more costly.

Secondly, the UCD process should involve the evaluation and measurement of product usage. Here, emphasis is placed on the behavioural measurements of ease of learning and ease of use very early on in the design process through the development and testing of prototypes with actual users. Metrics such as errors, assists and task completion rates

gauge this. In a usability test, users are given a prototype or the final product and asked to complete a series of typical tasks using the product. This activity is important to identify usability issues with the product. Then changes are made to improve the product before its release. As a result, the products become more efficient, effective, and the safety aspect of the products is assured.

The final principle recommends the “Iterative Design” where once the requirements are collected, the product is designed modified, and tested repeatedly. As no matter how expert is the experimenter who executes each usability activity, no one gets all the information correct at the first time of trying. Thus, the development cycle needs to be iterated and the product fine-tuned within each cycle until all the problematic issues were resolved. This is sometimes more costly and takes more time.

In this study, user-centred design methods are considered relevant to achieving the objectives. Therefore, they need to be considered throughout the stages of this research and they will be discussed in the thesis.

4.6.3. EVALUATING THE POTENTIAL OF THE PROPOSED PROTOTYPE

The most important factor in the decision to adopt mobile systems is user perception of their value in terms of perceived usefulness and perceived ease of use (Mallat et al., 2009, Lu et al., 2005, Davis, 1985). Perceived usefulness is also called performance expectancy while perceived ease of use is also called effort expectancy (Bhattacharjee and Barfar, 2011). Davis et al. (1989) and Bhattacharjee and Barfar (2011) define perceived usefulness as the extent to which individuals believe that using a particular Information Technology (IT) will enhance their job performance, while perceived ease of use is the extent to which users believe that learning how to use an IT and actually using it will be relatively free of effort.

Among a variety of theoretical perspectives to explain the adoption and usage of Information Systems (IS), the technology acceptance model (TAM) is popularly used to explain a user’s intention to adopt a target IS (King and He, 2006, Kim et al., 2009). Actually, TAM is an intention-based model stipulating that the intention to adopt a technology is a good predictor of its actual usage (Hong et al., 2006, Davis, 1985). It was introduced by Fred Davis in his doctoral thesis at the MIT Sloan School of

Management (Davis, 1985). He proposed that users' intention to adopt an IT is explained by perceived ease of use and perceived usefulness which are influenced by the system design characteristics (represented by X1, X2 and X3 in Figure 4-5). Perceived usefulness is, in turn, influenced by perceived ease of use (Davis, 1985).

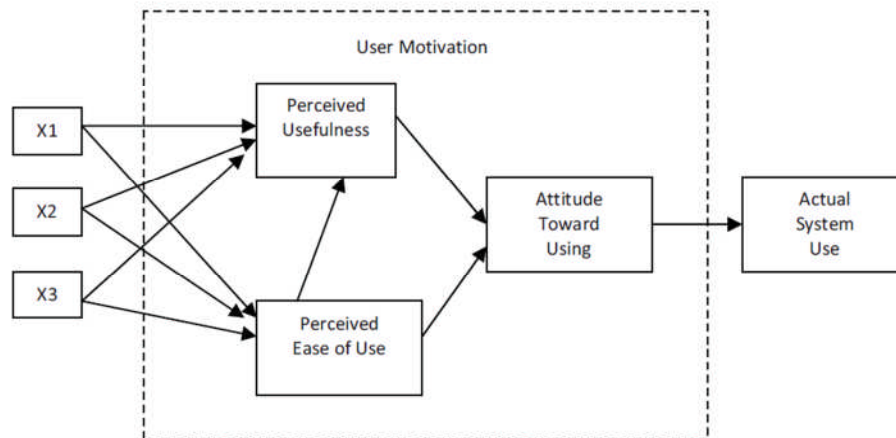


Figure 4-5 The Technology Acceptance Model (TAM) (Davis, 1985)

In the context of the mobile internet, Hong et al. (2006) have also concluded that TAM is the most economical and generic model that can be used to study both initial and continued mobile internet adoption. For that reason, TAM is being used in many of the studies on mobile internet acceptance and continuance. Son et al. (2012), for example, adopted TAM to explore the determinants of user satisfaction with mobile computing devices and the link between user satisfaction and perceived performance among construction professionals, while Mallat et al. (2009), by utilising TAM, proposed that perceived ease of use and perceived usefulness has a direct positive effect on consumers' intention to use a mobile ticketing service. Other examples of studies of systems using TAM include the work of Park (2009) on e-learning, Lai and Li (2005) on Internet banking and Ha and Stoel (2009) on e-shopping. As shown in abovementioned studies, perceived ease of use and perceived usefulness can be identified using both questionnaires and interviews.

4.7. RESEARCH METHODOLOGY ADOPTED AND JUSTIFICATION

According to (Yin, 2003), the selected research methodology should be based on a particular research philosophy. It should also be able to describe the whole research process, the methods, the extent of control the researcher has over actual behavioural events and the degree of focus on contemporary events. However, through reference to the literature, it is realised that there is no one best way for undertaking a research project. Therefore, different issues have been considered in determining the most appropriate approach for achieving the research aims and objectives for this study. Additional to the considerations of cost and the time and resources available, other aspects are also deemed important to this research and are listed below:

- The focus of the research is on environmental surveillance at construction sites;
- There is a need for rich primary data to allow an understanding of the user requirements;
- The aim is to prove the concept of mobile web usage as a tool for managing environmental surveillance activities at construction sites by members of environmental management, and
- The researcher's personal experience and knowledge.

In order to achieve the aims of this research, Design Science Research (DSR) has been chosen as the philosophical approach and case study as the research method. As for being systematic, this research will follow the methodology of the general design cycle (GDC) which was introduced by Takeda et al. (1990). The decision to choose DSR as the philosophical approach and case study as the research method was based on the discussions which are undertaken in the following paragraphs.

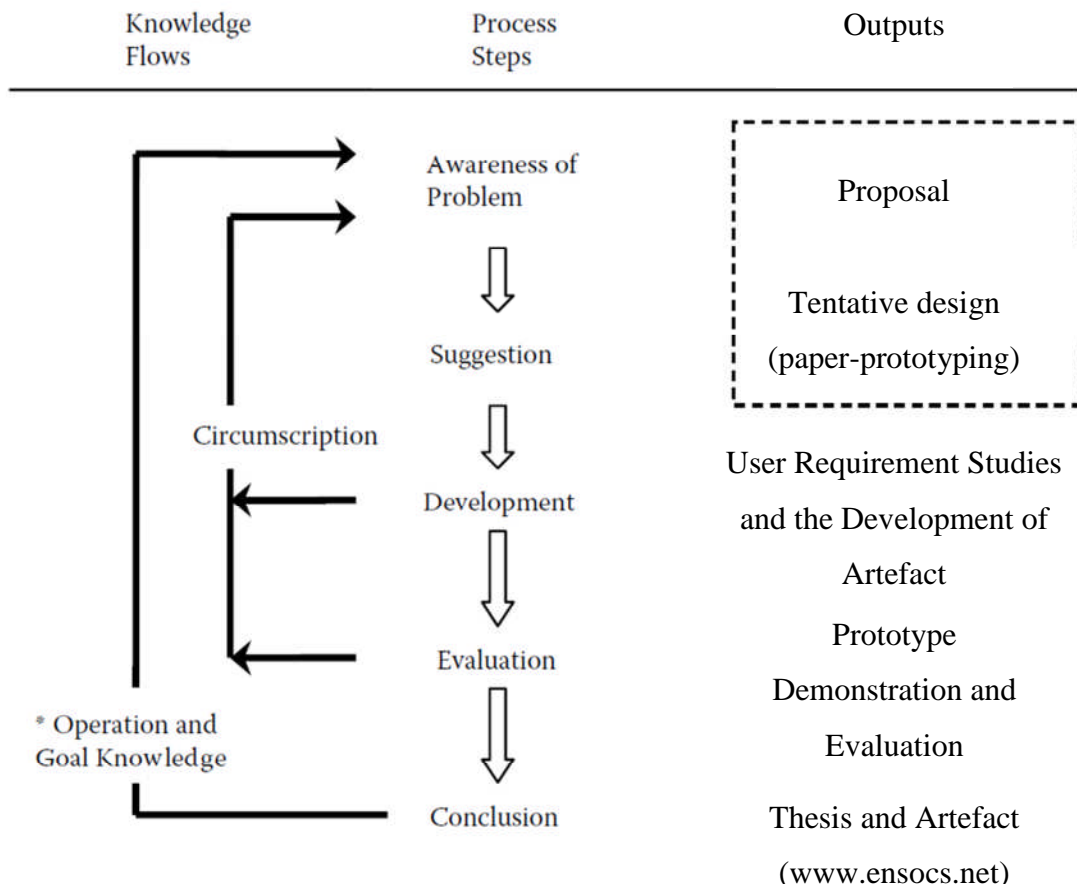


Figure 4-6 Research Methodology and the Output of this Research

Design is fundamental to the Information Systems (IS) discipline (March and Storey, 2008). Similarly, in design science research and practice, the internal design cycle is the heart of any design science research project (Hevner, 2007). IS researchers are engaged in the design of information technology (IT) artefacts as the research's central outcome is aimed at improving the performance of organizations and/or processes. This cycle of research activities iterates rapidly between the construction of an artefact, its evaluation, and subsequent feedback to refine the design further (Hevner, 2007, March and Smith, 1995). IT artefacts, in this case, refer to four types of IT artefacts as suggested by March and Smith (1995) and Hevner et al. (2010): constructs (a set of vocabulary and symbols), models (abstractions and representations), methods (algorithms or practices), and instantiations (implemented and prototyped systems).

The design cycles, however, depend on the requirements as the input from the relevance cycle. Good design science research often begins by identifying and representing

opportunities and problems in an actual application environment (Hevner, 2007). Thus, the relevance cycle initiates design science research with an application context that not only provides the requirements for the research (e.g., the opportunity/problem to be addressed) as inputs but also defines the acceptance criteria for the ultimate evaluation of the research results (Hevner, 2007).

In addition, design science draws from a vast knowledge base of scientific theories and engineering methods that provide the foundations for rigorous design science research (Hevner, 2007). In this case, the rigor cycle provides past knowledge to the research project to ensure its innovation. Research rigour in design science is predicated on the researcher's skilled selection and application of the appropriate theories and methods for constructing and evaluating the artefact. Figure 4-7 illustrates the three cycle view of design science research.

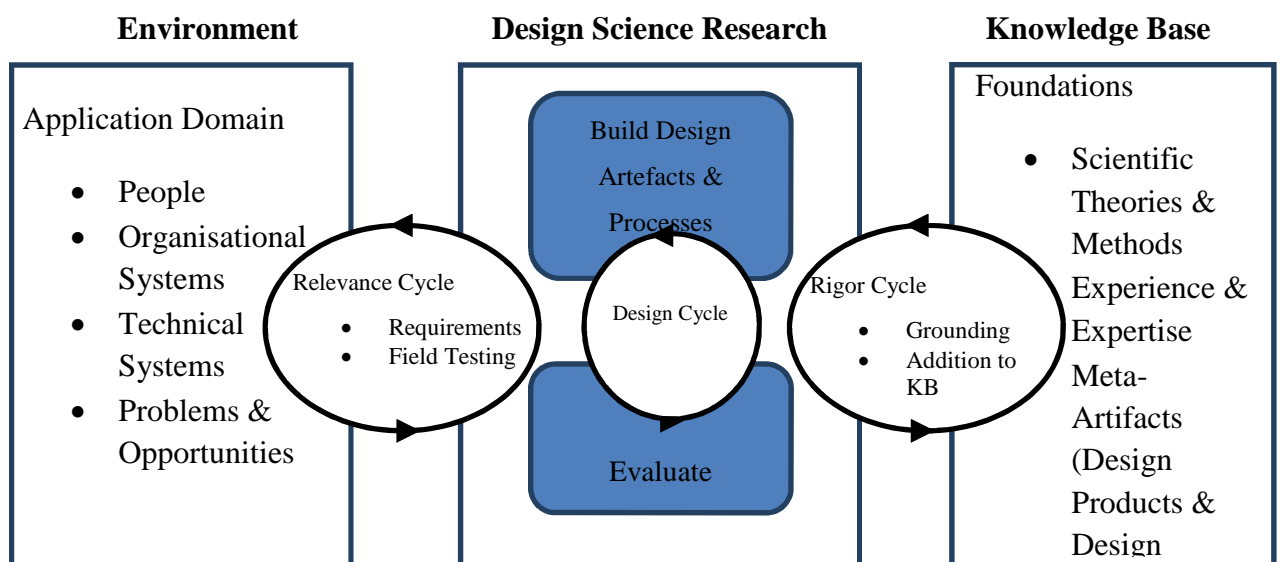


Figure 4-7 Design Science Research Cycles (Hevner, 2007)

Along the process, design science research adds to the knowledge base which can be represented in design artefacts as tacit gut feeling, as codified knowledge, or as scientific theories (Müller and Thoring, 2010). It will include the new meta-artefacts (design products and processes), any extensions to the original theories and methods made during the research, and all the experiences gained from performing the research and field testing the artefact in the application environment (Hevner, 2007). Research

contributions to the knowledge base are key to selling the research to the academic audience just as useful contributions to the environment are the key selling points to the practitioner audience.

Müller and Thoring (2011), by using the typology of design knowledge as proposed by themselves in their earlier research (Müller and Thoring, 2010) have explained the relationship between the design knowledge and the artefacts, in shown in Figure 4-8.

Levels of Design Knowledge	Type	Artifact Type	Hevner et al.	Representation	Design Example
D Model Level (Models and Theories)	Design Theories			Testable Design Theories	Golden Ratio, Design Patterns, Ergonomic Norms
Transition C→D Theory Formation / New Concepts					
C Symbolic Level (Explicit Knowledge)	Design Rational		Concepts	Design Terminology, Drawings, Modelmaking, Design Rules, Design Rational	Technical Drawings, Instruction Manual for Machines, Material and Production Knowledge
Transition B→C Externalise / Internalise					
B Neuronal Level (Tacit Knowledge)	Design Intuition		Methods & Practices	Design Intuition, Design Skills	Trial-and-Error, Master-Apprentice-Relation
Transition A→B Filtering / Adjust Filters					
A Physical Level (3D Form & Instantiations)	Design Artifacts	Prototypes Products	Instantiations	Form, „Gestalt“, Embodied Knowledge	Bottle Opener, Bionics

Figure 4-8 The Relationship Between the Design Knowledge and the Artefacts (summarised from Müller and Thoring (2011) and Müller and Thoring (2010))

In the context of this research, the design artefact refers to the developed prototype mobile web based environmental information system which is better known as “ENSOCS” (see www.ensocs.net). The motivation for this research was derived from the reviews of the disadvantages in the current traditional method and the identification of new opportunities that can improve environmental surveillance on construction sites particularly in Malaysia. It is anticipated that the ENSOCS mobile web could improve environmental surveillance processes by providing a tool for an environmental management team to manage their environmental surveillance activities and to enhance their decision-making capabilities. Thus, this research will investigate the potential of, and demonstrate, a mobile environmental information system for environmental surveillance.

For the context of the research, Yeoh et al. (1988) suggest that any approaches and systems introduced must suit the local context and, thus in this case, be in line with Malaysia’s strategy for environmental management. Yeoh et al. argue that it is desirable

that, at least in specific cases, indigenous technologies appropriate to the local situation be developed through research studies. In the context of Malaysia, there is a potential for the provision of ICT tools specifically for the construction industry. It is based on the availability of ICT infrastructures and IT friendly policies and initiatives put in place by the government of Malaysia. On the other hand, as the UK is well known as a one of the top-tier performers in the world in the Environmental Performance Index (EPI) and is no stranger to the use of ICT, it is more valuable for this research if a UK construction site and its participants are used as a case study and for triangulation as well. In fact, it is common for developing countries to follow the best practices and strategies used in ICT implementation in developed countries (Chen et al., 2006). Furthermore, it is believed that past experience of using similar technologies contributes greatly to favourable attitudes towards using a new technology and its actual adoption (Lu et al., 2003, Dabholkar, 1996).

For these reasons, construction sites in Malaysia and the UK have been chosen for the case studies for this research. Thus the prototype can be developed by taking into account the views and requirements of users in Malaysia as well taking advantage of input from the more experienced users in the UK, as an added value.

4.7.1. RESEARCH METHODOLOGY

The research approach for this research leverages on Design Science Research (DSR). While explanatory research seeks to produce theoretical knowledge, design science research aims to “produce and apply knowledge of tasks or situations in order to create effective artefacts” in order to improve practice (March and Smith, 1995). Similarly, this research follows the general design cycle (GDC) as described by Vaishnavi and Kuechler (2004) to address the research questions and to produce an artefact in order to add value to the current practices of environmental surveillance on the construction sites. To justify the whole research methodology of this research, the next sections will provide a justification that is based on the process steps within the general design cycle framework.

4.7.1.1. AWARENESS OF PROBLEM

The first step of the GDC framework is an awareness of a problem through problem identification and definition. In an effort to properly define the problem, a research sub-phase was identified and a literature review was carried out.

According to Neuman (2007), there are four main goals to a literature review:

- To demonstrate familiarity with a body of knowledge and establish credibility.
- To show the path of prior research and how a current project is linked to it.
- To integrate and summarise what is known in an area.
- To learn from others and stimulate new ideas.

The problems identified in the literature review indicate that, currently, most environmental personnel within the Malaysian construction industry still rely on traditional communication tools (e.g. letters, e-mails, faxes and telephones) and paper-based documents (e.g. the paper form of checklists, plans and manuals) while performing environmental surveillance and, subsequently, manual reporting and record keeping processes e.g. paper-based reporting and filing cabinets. Such activities are time consuming and labour-intensive and are exposed to deficiencies and discrepancies, etc.

Therefore, in the context of this research, a literature review was initiated to (1) gain an understanding of the current practices of project managers and environmental officers; (2) determine that the problem has not been previously solved and determine what, if any, research has previously been performed in the area; (3) determine that the problem is widespread and that the solution will provide an interesting contribution to practice and academic communities, and (4) define and scope the problem as appropriate for the resources available to the research. In order to complete the research sub-phase, two main topics (construction and the environment and mobile web and devices) were selected and reviewed and have been discussed previously in Chapters 2 and Chapter 3. An evaluation of tools used by environmental officers for environmental surveillance on construction sites was also conducted and included in these two chapters. This evaluation provided further evidence that academic or practitioner communities have not previously solved the problem and offered inspiration for the continuation of the research.

4.7.1.2. SUGGESTION

Having identified the problem, research was necessary to derive suggestions to address the research problem. In this research, it was found that the mobile web as a tool for environmental officers would improve environmental surveillance processes. To develop the prototype mobile web as a tool for environmental officers, it is important to understand the users and obtain their requirements concerning mobile environmental information systems.

Courage and Baxter (2005) argue that the single most critical activity in developing a quality product is understanding who the users are and what they need, and documenting it. A failure to do this means that the product might be doomed to failure. Thus, to understand more about users, Courage and Baxter recommend that the process start with developing a user profile – a detailed description of the users' attributes (job title, experience, level of education, key tasks, age range, etc.). Later, after the creation of a thorough user profile, personas (exemplars of the end user) and scenarios (a day-in-the-life of the end user) have to be developed. Personas are designed to help keep specific users in focus during design discussions. Scenarios help the researcher to test the system and to build functionality into the product that users will actually want to use.

Once all these three aspects have been prepared then the user requirements' study can take place. There are a variety of user requirements techniques and each of them provides different information and has different goals. Courage and Baxter (2005) have made a comparison of each technique as shown in Table 4-4 Comparison of user requirements techniques.

Table 4-4 Comparison of user requirements techniques

Method	Purpose	Advantages	Level of Effort	Relative Time
Interviews	Collecting in-depth information from each of several users	<ul style="list-style-type: none"> • A skilled interviewer can collect a lot of information from each user • Flexible: you can ask follow-up questions & delve into more detail than with surveys or focus groups 	<ul style="list-style-type: none"> • If you are not a skilled interviewer, training is required • It takes time to interview enough users 	Medium (telephone interviews) to high (on-site interviews)
Surveys	Quickly collects quantitative data from a large number of users	<ul style="list-style-type: none"> • Collects information from a large number of users simultaneously • If designed correctly, it can be quick & easy to analyse the data • Relatively cheap 	<ul style="list-style-type: none"> • The evaluator must be skilled in creating unbiased surveys (this requires training) • If it is posted to the web, little effort is required to distribute it 	Medium

Method	Purpose	Advantages	Level of Effort	Relative Time
Wants' and needs' analysis	Collecting a prioritized list of users' perceived wants and needs	<ul style="list-style-type: none"> • Can prepare for, conduct, and analyse data from, the activity in a short period of time & with few resources 	<ul style="list-style-type: none"> • Group moderations take moderate effort • Recruiting enough users can be resource intensive • Effort to conduct & analyse data is low 	Low
Card Sort	Identifying how users group information or objects to inform product information architecture	<ul style="list-style-type: none"> • Relatively simple technique to conduct • If run as group, can collect data from several users at once • Encourages the product team to better understand their own product by breaking the product 	<ul style="list-style-type: none"> • It can be hard work to come up with list of information or objects & definitions • Effort to conduct the activity is low • Effort required to analyse data varies depending on tool, 	Low (group card sort) Medium (individual card sort)

Method	Purpose	Advantages	Level of Effort	Relative Time
		down & defining each component	number of cards and number of participants	
Group Task Analysis	Understanding how users complete a specific task & issues surrounding that task	<ul style="list-style-type: none"> • Develops a task flow that works for multiple users/ companies • Quick to conduct • Relatively cheap 	<ul style="list-style-type: none"> • Group moderation requires high effort • Fast turnaround on results • Analysing the data requires low effort 	Low
Focus Group	Assessing user attitudes, opinions, & impressions	<ul style="list-style-type: none"> • Recruiting enough users can be resource intensive • Collects data from several users simultaneously • Group discussion often sparks new ideas 	<ul style="list-style-type: none"> • Group moderation takes moderate effort • Summarizing the data requires relatively low effort 	Low
Field Studies	Learning about the users, their environment,	<ul style="list-style-type: none"> • Not dependent on what someone says they do 	<ul style="list-style-type: none"> • Arranging the visits, conducting them, & then 	Medium to high

Method	Purpose	Advantages	Level of Effort	Relative Time
	& tasks in context	<ul style="list-style-type: none"> • Can collect a plethora of rich data • Ecological Validity 	analysing the data requires a higher level of effort than any of the previous methods	

As can be seen from Table 4-4, in-depth information from each user can be obtained through interviews and this cannot be obtained through another activity (e.g., group task analysis, survey, etc.). Furthermore, from the combination of conducting interviews with multiple user types from the same process/system/organization, one can obtain a holistic view (Courage and Baxter, 2005).

However, in the context of this research, by taking into account the researcher's eight years' experience in environmental surveillance, some user requirements have already been identified and this facilitates the preparation of the paper-based prototype. Therefore, any additions which came out of the literature review and validation through semi-structured interviews would add value to the user requirements of the system.

Thus, the user requirement studies for this research have been conducted through semi-structured interviews and the presentation of the paper-based prototype to experts (Environmental Managers) in Malaysia. Respondents were selected on the basis that their organisations are prominent players in the construction industry and because they are currently managing the environmental aspects and impacts of a project and are actively participating and contributing to the UK and Malaysian construction industries. They were project managers, environmental managers and officers in organisations with vast experience and knowledge of the subject matter. In this research, the users from the UK and Malaysia were chosen for the user requirement studies in order to:

- a. Identify requirements from different perspectives and working environments so that the application or system provided is robust and able to meet the needs of various types of users and construction environments, and

- b. Achieve greater research integrity as the findings are to be shared and compared as the project progresses.

To gain more information about each user, the researcher developed questionnaires to gather their background information and interviewed them on how they normally conduct environmental checking and corrective action. The web-based scenarios were then discussed and the users were asked to figure out the features were required in order to perform each scenario. At the end of the session, user walkthroughs of the low-fidelity prototypes were performed and the proposed features of the website were explained simultaneously to get the participant's buy-in.

4.7.1.3. DEVELOPMENT

The findings from the user requirement exercise became the foundation for the development of a particular system. Similarly to this research, the ENSOCS mobile web was developed by referring to the inputs from the expert interviews and the development was carried out according to the prominent system development methods.

A system development method refers to the framework that is used to structure, plan, and control the process of developing a system (Centers for Medicare & Medicaid Services (CMS), 2005). There are many types of methods and each of it has own strengths and weaknesses. According to Zhao (2012), the selection of an appropriate method should depends on the project size, software complexity, system architecture, number of stakeholders, time pressure, development power, details specifications, business constraints and affordability of tools. Table 4-5 discuss the advantages and disadvantages of the system development methods.

Table 4-5 The Advantages and Disadvantages of the System Development Methods
(Isaias and Issa, 2015, Zhao, 2012, Green and DiCaterino, 1998)

Development Approaches	Advantages	Disadvantages
The Waterfall Model	<ul style="list-style-type: none"> • Ideal for supporting less experienced project teams and project managers, or project teams. • The orderly sequence of development steps and strict controls for ensuring the adequacy of documentation and design reviews helps ensure the quality, reliability, and maintainability of the developed software. • Progress of system development is measurable. • Conserves resources. 	<ul style="list-style-type: none"> • Inflexible, slow, costly and cumbersome. • Depends upon early identification and specification of requirements, yet users may not be able to clearly define what they need early in the project. • Problems are often not discovered until system testing. • Difficult to respond to changes. • Produces excessive documentation and keeping it updated as the project progresses is time-consuming.
The Prototyping Model	<ul style="list-style-type: none"> • Not a standalone, complete development methodology, but rather an approach to handling selected portions of a larger, more traditional development methodology (i.e., Incremental, Spiral, or Rapid Application Development (RAD)). • Attempts to reduce inherent project risk by breaking a project into smaller 	<ul style="list-style-type: none"> • Approval process and control is not strict • Incomplete or inadequate problem analysis may occur • Requirements may frequently change significantly • Designers may neglect documentation • Iterations add to project budgets and schedules

Development Approaches	Advantages	Disadvantages
	<p>segments and providing more ease-of-change during the development process.</p> <ul style="list-style-type: none"> • User is involved throughout the process, which increases the likelihood of user acceptance of the final implementation. • Improves both user participation in system development • Useful for resolving unclear objectives • Identify confusing or missing functionality • Encourages innovation and flexible designs • Provides quick implementation of functional applications. 	
<p>The Incremental Approach</p>	<ul style="list-style-type: none"> • Potential exists for exploiting knowledge gained in an early increment • Stakeholders can be given concrete evidence of project status throughout the life cycle • Helps to mitigate integration and architectural risks earlier in the project. 	<ul style="list-style-type: none"> • There might be usually a lack of overall consideration of the business problem and technical requirements for the overall system • Since some modules will be completed much earlier than others, well-defined interfaces are required • cell-content

Development Approaches	Advantages	Disadvantages
	<ul style="list-style-type: none"> • Allows delivery of a series of implementations that are gradually more complete 	<ul style="list-style-type: none"> • Difficult problems tend to be pushed to the future to demonstrate early success
The Spiral Approach	<ul style="list-style-type: none"> • Enhances risk avoidance • Can incorporate waterfall, prototyping and incremental approaches 	<ul style="list-style-type: none"> • Highly customized to each project, and thus is quite complex, limiting reusability. • A skilled and experienced project manager is required
Rapid Application Development	<ul style="list-style-type: none"> • The operational version of an application is available much earlier than with Waterfall, Incremental, or spiral frameworks. • Fast and thus, it tends to produce systems at a lower cost. • Engenders a greater level of commitment, thus, creates more senses of ownership of a system among the users. • Concentrates on essential system elements from user viewpoint. Provides the ability to rapidly change system design as demanded by users. • Produces a tighter fit 	<ul style="list-style-type: none"> • More speed and lower cost may lead to lower overall system quality. • Danger of misalignment of developed system with the business due to missing information. • Potential for violation of programming standards related to inconsistent naming conventions and inconsistent documentation. • Difficulty with module reuse for future systems. • Potential for lack of attention to later system administration needs built into system. • High cost of commitment on the part of key user personnel.

Development Approaches	Advantages	Disadvantages
	<p>between user requirements and system specifications.</p> <ul style="list-style-type: none"> • Generally produces a dramatic savings in time, money, and human efforts. 	<ul style="list-style-type: none"> • Formal reviews and audits are more difficult to implement than for a complete system. • Since some modules will be completed much earlier than others, well-defined interfaces are required.

Therefore, as a system development methodology is not necessarily suitable for use by all projects (Fathi, 2009), the researcher considered each of the major prescribed approaches, especially in context of this research, its applications, its timeline and technical environments. As a result, this research will use the Prototyping Approach as a web development approach. This development approach will be integrated into the overall research methodology that has been discussed in an earlier section.

There were a few reasons behind the selection of the Prototyping Approach as the web development approach. It was mainly due to the following reasons:

- a. This research has clear objectives and solutions.
- b. The research requirements are stable or unchanging during the web development life cycle. However, it is anticipated that the functional requirement of the web may change frequently and significantly. Thus, the prototyping approach was chosen to handle the changes.
- c. The target users are environmental professionals working on construction sites who are fully knowledgeable about environmental management. This hopefully would expedite the process of confirmation of the user requirements.
- d. The researcher has little experience in terms of developing the web even though he has gained much knowledge throughout eight (8) years of experience in the field of environmental management and has conducted more than 650 environmental inspections and audits on construction sites.
- e. Strict requirements exist for formal approvals at designated milestones.

4.7.1.4. EVALUATION

Evaluation is an assessment of all data collected during the monitoring process (both quantitative and qualitative) with a view to checking that the users can operate the product (application) and that they like it, particularly if the design concept is new (Fathi, 2009). It is one way of ensuring that there are no negative outcomes from the usage of the systems. It also ensures that the system is well adapted to the users and their tasks, so that the changes and improvement can be made, if necessary (Kallio and Kaikkonen, 2005). Evaluation can be conducted in two ways: functional evaluation and usability evaluation.

Functional evaluation of an application is evaluated through the use of a test case. Test case features documentation specifying inputs, predicted results and a set of execution conditions for a test item (IEEE Standard 610.12, 1990). Usability evaluation is a process that employs people (who are representative of the target audience) as testing participants to evaluate the degree to which a product meets specific usability criteria (Rubin and Chisnell, 2008a). Usability evaluation can be undertaken in many ways. Certain methods make use of the data gathered from users, while others rely on usability experts. However, it is important to consider the cost, time constraints and appropriateness of the method when choosing a usability testing method for a particular project (Fathi, 2009). Table 4-7 briefly describes each method and their advantages and disadvantages.

According to Bastien (2010), there are three main reasons why people should undertake usability evaluation:

- Informing design
- Eliminating design problems and frustration
- Improving profitability

With regards to the methods, testing and inspection are the two main methods in conducting a usability evaluation. And to differentiate between those two, the inspection is mainly a set of methods where an evaluator inspects a user interface whereas usability testing is where the usability of the interface is evaluated by testing it on real users (Nielsen, 1994). In selecting the most appropriate usability testing methods, the researcher categorised the methods, type, aspect, remote evaluation and the data of usability testing as shown in Table 4-6. This was to make sure that the selected

approach was suitable for users working both in the UK and Malaysia. It was important to identify which methods could be conducted remotely in order to obtain quantitative data.

Table 4-6 The Type and Issues Covered in Usability Testing (Fathi, 2009)

No	Evaluation Method	Evaluation Method Type		Usability Issues Covered			Can Be Conducted Remotely.	Can Obtain Quantitative Data.
		Testing.	Inspection.	Effectiveness:	Efficiency:	Satisfaction:		
1	Focus Group	X		Yes	No	Yes	No	No
2	Interview	X		Yes	No	Yes	Yes	No
3	Field Observation	X		Yes	No	Yes	No	No
4	Remote Testing	X		Yes	Yes	Yes	Yes	Yes
5	Thinking-Aloud Protocol	X		Yes	No	Yes	No	No
6	Cognitive Walkthrough		X	Yes	No	No	No	No
7	Pluralistic Walkthrough		X	Yes	No	Yes	No	No
8	Heuristic Evaluation		X	Yes	Yes	No	Yes	No
9	Questionnaires	X		Yes	Yes	Yes	Yes	Yes

The comparison shows that interviews, heuristic evaluation (the ease of use in particular) and questionnaires are able to complement each other. This makes them the most appropriate methods for usability testing in this research. This combination of the methods selected covers both testing and inspection types and all three usability issues. In addition, they can be conducted remotely.

Table 4-7 The Advantages and Disadvantages of Usability Testing Methods

Evaluation Method	Description	Advantages	Disadvantages
Ethnographic Studies	This method can be performed via observation of users in the place where they would normally use the product (e.g., work, home, coffee bar, etc.). It gathers data about who the target users are, what tasks and goals they have relating to the planned product (or enhancements), and the context in which they work to accomplish their goals (Rubin and Chisnell, 2008a).	<ul style="list-style-type: none"> • Simply examines real-life settings in real workplaces. 	<ul style="list-style-type: none"> • Applicable in the final testing, at least when using prototypes. • A relatively large number of users needed (20+). • Required expertise is high. • It needs a longer period to complete.
Interview	An interview is a purposeful discussion between two or more people (Saunders et al., 2009). In the context of information systems, an interview is carried out to gather valid and reliable data about a user's experience and expectation. It can be a structured, unstructured or semi-structured interview or a	<ul style="list-style-type: none"> • Good at obtaining detailed information. • Few participants are needed. • Can improve customer relations. 	<ul style="list-style-type: none"> • Does not address the usability issue of efficiency.

Evaluation Method	Description	Advantages	Disadvantages
	<p>group interview (Myers and Newman, 2007). The purpose of the interview at the beginning stage of development is to formulate questions about the product based on the kinds of issues of interest (Rubin and Chisnell, 2008a). Interviews can also be undertaken at the last stage of development if they are concerned with clarifying user responses and collecting additional information (Vatrapu and Perez-Quinones, 2006).</p>		
Participatory Design	<p>Often used for the development of in-house systems, this approach employs one or more representative users on the design team itself. In short individual workshops, users, designers and developers work together on an aspect of design. It enables the design and development team to tap the user's</p>	<ul style="list-style-type: none"> • Engagement with the users starts from commencement, thus creating a sense of ownership among the users. • Easy to get the feedback from the users. 	<ul style="list-style-type: none"> • The potential danger is that the representative users can become too close to the design team. They begin to react and think like the others or, by virtue of their desire to avoid admonishing their colleagues, withhold important concerns or

Evaluation Method	Description	Advantages	Disadvantages
	knowledge, skill set, and even emotional reactions to the design (Rubin and Chisnell, 2008a).		criticism.
Focus Group	A moderator guides a discussion with a group of users of the application. Powell and Single (1996) define a focus group as “a group of individuals selected and assembled by researchers to discuss and comment on, from personal experience, the topic that is the subject of the research”.	<ul style="list-style-type: none"> • If undertaken before prototypes are developed, can save money. • Produces a lot of useful ideas from the users themselves. • Can improve customer relations. 	<ul style="list-style-type: none"> • The environment is not natural for the user and may provide inaccurate results. • The data collected tends to have low validity due to the unstructured nature of the discussion. • The time it takes to conduct focus group research may discourage many from attempting to collect data using this method (Gibbs, 1997)
Remote Testing	The experimenter does not directly observe the users while they use the application. However, it must be universally accessible, it	<ul style="list-style-type: none"> • Efficiency, effectiveness and satisfaction, the three usability issues, are covered. 	<ul style="list-style-type: none"> • Additional software is necessary to observe the participants from a distance.

Evaluation Method	Description	Advantages	Disadvantages
	<p>must be shared efficiently by a large number of users and it must function automatically (Hartson et al., 1996). Furthermore, the system should provide maximum flexibility whilst presenting a minimal learning curve (Knight and DeWeerth, 1996).</p>		
Thinking-aloud Protocol	<p>Participants in the testing are required to speak aloud in expressing their thoughts on the application while executing set tasks (Oh and Wildemuth, 2009). By showing how users interpret each individual interface item, the thinking-aloud protocol facilitates a direct understanding of which parts of the dialogue cause the most problems (Nielsen, 1993).</p>	<ul style="list-style-type: none"> • Less expensive • Results are close to what is experienced by users. 	<ul style="list-style-type: none"> • The environment is not natural for the user.
Cognitive Walkthrough	<p>A team of evaluators walks through the application discussing usability issues through the use of a paper prototype or a working</p>	<ul style="list-style-type: none"> • Good at refining requirements. • Does not require a fully functional prototype. 	<ul style="list-style-type: none"> • Does not address user satisfaction or efficiency. • The designer may not behave as the

Evaluation Method	Description	Advantages	Disadvantages
	<p>prototype. A cognitive walkthrough is a task-oriented method by which the analyst explores the system functionalities (Wharton et al., 1994). A cognitive walkthrough involves one or a group of evaluators inspecting a user interface by going through a set of tasks and evaluating its understandability and ease of learning (Nielsen and Mack, 1994).</p>		<p>average user when using the application.</p>
<p>Pluralistic or Group Walkthrough</p>	<p>A team of users, usability engineers and product developers reviews the usability of the paper prototype of the application.</p>	<ul style="list-style-type: none"> • Usability issues are resolved more rapidly. • Greater numbers of usability problems can be found at one time. • Brings a diverse range of skills and perspectives to bear on usability problems (Sharp et al., 2007). 	<ul style="list-style-type: none"> • Does not address the usability issue of efficiency.
<p>Heuristic Evaluation</p>	<p>Identifies usability problems in the user interface design. It is one of the popular</p>	<ul style="list-style-type: none"> • Application of recognized and accepted principles. 	<ul style="list-style-type: none"> • Disassociation from end users. • Does not identify or allow for

Evaluation Method	Description	Advantages	Disadvantages
(HE)	<p>techniques proposed by Nielsen and Molich (1990b). The heuristic method consists of checking the software or tool against the standard usability principals, such as realistic user interface design, system status, user control and freedom, consistency, flexibility and ease of use.</p>	<ul style="list-style-type: none"> • Intuitive. • Usable early in the development process. • Effective identification of major and minor problems. • Rapidity. • HE can be used throughout the development process. 	<ul style="list-style-type: none"> • unknown user needs. • Unreliable, domain-specific, problem identification. • HE does not necessarily result in evaluating the complete design since there is no mechanism to ensure the entire design is explored; evaluators can focus too much on one particular section.
Paper Prototyping	<p>In this technique, the design and development team may mock up pages with paper and pencil, or on graph paper, or create line drawings or wireframe drawings of screens, pages, or panels, with a page version for each state (Rubin and Chisnell, 2008a). Then the mock up will be presented to the users. The users will be asked questions about it, or</p>	<ul style="list-style-type: none"> • Critical information can be collected quickly and inexpensively. • Technical writers might use the technique to evaluate the intuitiveness of their table of contents before writing one word of text. 	<ul style="list-style-type: none"> • Does not address the usability issue of efficiency.

Evaluation Method	Description	Advantages	Disadvantages
	asked to respond in other ways.		
Questionnaires	Questionnaires are one of the indirect testing techniques designed to assess usability. They can give valuable feedback from the user point of view.	<ul style="list-style-type: none"> • Subjective user preferences, satisfaction and possible anxieties can be easily identified. • Can be used to compile statistics. 	<ul style="list-style-type: none"> • Indirect methods result in low validity (discrepancies between subjective and objective user reactions must be taken into account); needs sufficient response to be significant. • Identifies only a low number of problems relative to the other methods.

4.8. SUMMARY

This chapter has reviewed, described and presented the research philosophies, research methodologies and research methods available to address the research problems. Design Science Research (DSR) has been chosen as the philosophical approach and case study as the research method. As for being systematic, this research will follow the methodology of the general design cycle (GDC) which was introduced by Takeda et al. (1990) and will combine multiple approaches in each design stage. The combination of multiple approaches and the design philosophy aims to demonstrate the potential applications of a mobile environmental information system in realistic construction situations. However, the design of a mobile environmental information system should be based on a thorough knowledge of the potential users of the mobile application and the situations in which the application is going to be used. It is important to meet the real users at the beginning of the project to establish relevant goals for the application so that it fulfils the user requirements. These will be the focus of the following chapter.

CHAPTER 5. USER REQUIREMENTS' ANALYSIS AND SYSTEM DESIGN

5.1. INTRODUCTION

Garrett (2010) argues that most people often think of designing a product in terms of functional and aesthetic appeal alone, but looking just at these aspects can cause a failure in design. Such products might look wonderful and work well functionally, but designing products with user experience as an explicit outcome means looking beyond the functional or aesthetic, in which by answering the question of context (Kujala, 2003). Of course, in this study, functional design ensures the stimulation of the appropriate action on the mobile web and devices whilst aesthetic design assures the button on the mobile web is of an attractive shape and texture. But user experience design, for example, makes sure that the button works in the context of what the user is trying to accomplish and asks questions such as “Is the button in the right place relative to the other controls the user will be using at the same time?” Due to such reasons, it is now widely understood that successful systems and products begin with an understanding of the needs and requirements of the users.

Thus, in order to design something to support people, the target users and their requirements need to be identified very carefully at the beginning of the design process (ISO 9241-210, 2010, Maguire and Bevan, 2002). The goal of performing a user requirements study is to investigate how the product should perform or what are the features/attributes that the product should have, from the users' perspective (Baxter and Courage, 2005, Minocha, 1999). This activity is fundamental to a user-centered approach and is very important in interactive design.

Specifically for this research, such an approach (as discussed in the study of Maguire and Bevan (2002)) has been used. It encompasses information gathering, user needs identification, envisioning and evaluation, and gathering requirement specifications in generating user requirements. Based on the user requirements, the system design goal, the conceptual model and the functional specifications for the prototype of the ENSOCS web were developed. The four stages of the approach, and the methods used to support

the stages, are described in the next sections, followed by a discussion on the ENSOCS architecture and its functional specifications which includes use-case, a use-case description and flow diagram, a high-level class diagram and the assumptions and dependencies of the functional specifications. The Figure below shows the overall process of development of the functional specifications of the ENSOCS web.

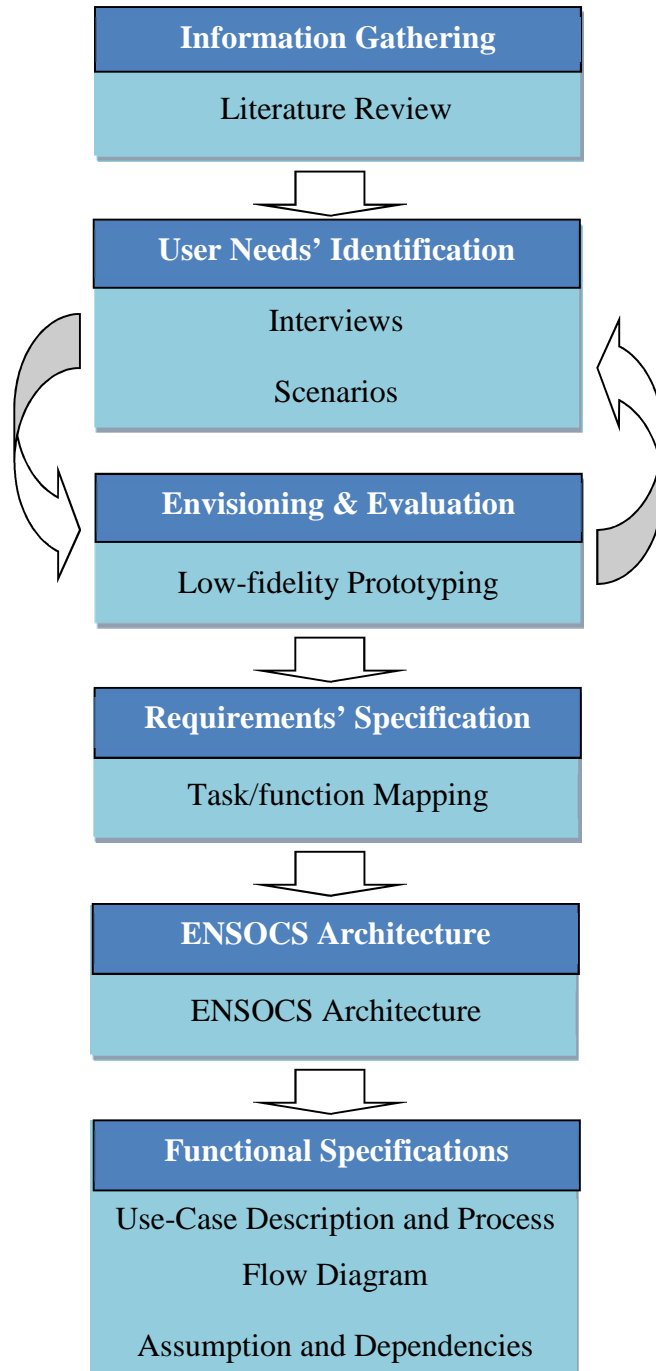


Figure 5-1 Steps for the Development of the Functional Specifications

5.2. USER REQUIREMENTS ANALYSIS

The most important aspect of the user requirement investigation in this research was the undertaking of explorative interviews with the domain experts. The exploratory interviews were in the form of guided semi-structured interviews. The aims of the interviews were to explore how those interviewed normally conducted the environmental surveillance, the current system adopted, their needs and the approach(es) used in their organisation.

A semi-structured interview was the preferred method of initial investigation in the study as it provides a guide for an interview whilst allowing the opportunity to ask spontaneous questions to glean further information. However, it is also important to note that this study is bound to the "Ethical Approval Studies by the University of Salford". Hence, all forms of data were sorted, encrypted and stored on a password protected computer, accessed only by the researcher and protected by the university Firewall. In term of personal data, all identifying personal information collected was anonymised by a code reference. The code reference and personal identity were kept in a separate portable disc available only to the researcher. Any direct quotations were also anonymised. The hard copy data were stored in a locked cabinet only accessible by the researcher while the digital data, such as interview recordings were deleted once transcription and triangulation has completed. The data will be kept 6 months after publication of the PhD by the researcher and will then be deleted.

Being discovery-orientated, interviews aim at expanding the interviewer's understanding of what attitudes and types of experiences exist. The information can then be analysed qualitatively. The interviews included four main sections: Section A covered the background of, and general information on, the respondents, Section B enquired about the current environmental management tools adopted by the respondents and Section C questioned the respondents concerning their information and service requirement for the prototype mobile web. A bit different to the other sections, in the Section D the respondents were given scenarios and were asked to figure out the features that were required in order to perform each scenario. The respondents then were asked to confirm the proposed potential applications through a discussion on the web-based scenarios and walkthroughs of low-fidelity prototypes. Each interview took about two and half hours. A set of relevant documents, research brief, authorisation

letter, interview questions, ethical approval form and other materials important for the readiness of the respondent for the interview session, was delivered prior to each session. The list of questions asked and the notes taken can be found in Appendix 3.

The collected information was then analysed which then led to the formulation of the system design goals and a conceptual model which, in turn, led to the creation of the functional specification. The data generated from the interviews were analysed using content analysis. QSR NVivo version 10 software was used to document and conduct the analysis. Interview coding ('node') was used to capture what was in the interview transcripts in order to capture the user requirements. nVivo software allows a user to highlight key points in the transcripts. nVivo's nodes allow storage of information on a summarised theme and nVivo's query tools allow a user to uncover subtle trends and gain automated analysis from the interview transcripts. The following section will discuss in detail the findings of each section within the interviews.

In this research, a total of four (4) environmental experts participated in the semi-structured interviews. They were selected on the basis that they were experienced personnel with a minimum of twelve (12) years and up to maximum of twenty-two (22) years of working experience in the construction industry and were currently managing the environmental aspects and impacts of projects and actively participating and contributing to the Malaysian construction industry. To gain more information about themselves, they were asked the questions from Section A (from the set questions) in order to gain their backgrounds information. The results are as shown below.

Table 5-1 Details of Expert Domain

Descriptions	Expert Domain			
Research ID.	EXMAL01	EXMAL02	EXMAL03	EXMAL04
Age	59	46	42	35
Job Position	General Manager	Environmental Manager	Environmental Manager	Environment al Manager
Working experience in the construction industry	16 years	15 years	22 years	12 years

Managerial experience	16 years	10 years	10 years	4 years
Non-managerial experience	-	5 years	12 years	8 years
Number of projects under current supervision	50 projects	25 projects	51 projects	1 project
Number of subordinates under current supervision	10 personnel	3 personnel	12 personnel	6 personnel

5.2.1. INFORMATION GATHERING

As discussed in Chapter 2, a walk-through inspection is unable to quantify and represent complete information on the physical, chemical and biological characteristics of the monitoring parameters, hence using technological based surveillance via wireless sensor networks is deemed important. However, with technological based surveillance it is difficult to demonstrate a connection between any pollution detected and a specific source. Therefore, it could be better for the proposed gathering of mobile environmental information for environmental surveillance on the construction sites to capitalise on the advantages of these two approaches: physical surveillance (observation/walk-through inspection) and technological based surveillance (wireless sensor networks).

There are ten (10) phases within the inspection process but the actual inspection actually starts with an opening conference to explain the inspection process to the facility and ends with a closing conference, in which the inspector may make facility managers aware of any violations, may prescribe corrective actions and explain the consequences of continuing non-compliance (International Network for Environmental Compliance and Enforcement (INECE), 2009). However, because the aim of this research is to provide environmental managers with a tool for environmental surveillance, only some part of these ten (10) phases were considered to be in-scope. Table 5-2 explains the reason behind the choices as to whether they were in-scope or out of scope.

Table 5-2 In-Scope within/Out-of-Scope of the research

Nos.	Activities	Description	Justifications
1	Targeting Inspections	The considerations in selecting sites and sectors to be inspected are influenced by the enforcement history, by potential threats, complaints or information from the public or other external sources and emergency responses towards incidents/accidents on sites.	Out-of-Scope Addressing inspection planning is beyond of the scope of this research. However, the prototype will provide some information that would support users in making decisions.
2	Preparation of an Inspection Plan	This phase entails tasks such as reviewing all available information, contacting everyone who may have relevant information, getting administrative clearances and making the necessary arrangements if samples need to be taken.	Out-of-Scope Addressing inspection planning is beyond of the scope of this research. However, the prototype would become a source of information as it will help users to familiarize themselves with the sites through the display of some of the related information.
3	Entry into Facility	Most public agencies seek to obtain consensual entry first. If the entry is denied, they try to explain again why the entry is necessary. If denied again, authorization to enter may be granted by a legal authority.	Out-of-Scope Addressing inspection planning is beyond of the scope of this research.

Nos.	Activities	Description	Justifications
4	Opening Conference	The purpose of an opening conference is to let the facility know what the agency plans to do and why. It is also set up to learn more about the facility operation, plant layout, management structure, plant processes, plant safety and other information relevant for the investigation.	<p>Out-of-Scope</p> <p>The opening conference is normally conducted in the form of meetings and a discussion. The existing procedures will be maintained but the prototype will provide relevant information which will be valuable in the opening conference.</p>
5	Collecting Evidence in the Field	Evidence is anything that provides verifiable information that can be used to establish, certify, prove, substantiate or support an assertion. It can include physical samples, photographs and copies of facility documents. The two most common methods of collecting evidence in the field are a facility walk-through and process-based investigations. Interviews are also one of an inspector's most useful tools for gathering information.	<p>In-Scope</p> <p>The prototype will provide visibility on the mobile device on the real-time environmental monitoring status. Thus, the environmental management team will always be aware of the environmental quality status on site. In addition, the prototype will offer the capabilities of the mobile web and the mobile devices so that users may use it as a tool for surveillance.</p>
6	Collecting Evidence from Records and	A record is any means of memorializing an event, person, place or thing. Inspectors have	<p>In-Scope</p> <p>The surveillance activities will be benefited the</p>

Nos.	Activities	Description	Justifications
	Reports	<p>the authority to review relevant firm records to determine compliance. The following are some common records that may be of relevance for inspectors: annual reports; production records; shipping reports; manifests; inventory records; sales reports; process records; permits; quality control records; waste management records; documentation on environmental management systems; employee training records; self-monitoring records; discharge monitoring reports; licenses; articles of incorporation; property records; logs; maintenance records; spill reports; safety records, and accident reports.</p>	evidence from records and reports.
7	Closing Conference	<p>The closing conference provides an opportunity to confirm the inspectors' observations and to review the preliminary findings with facility personnel. This may also be the opportunity to explain observed violations to the company.</p>	<p>In-Scope</p> <p>The closing conference is normally conducted in the form of meetings and a discussion. The existing procedures will be maintained but users can have a discussion with the site personnel and refer to the surveillance findings and real-time data on the</p>

Nos.	Activities	Description	Justifications
			mobile devices.
8	Report Writing	The objective for generating the report is to organize and coordinate all documentation and potential evidence in a comprehensive, understandable and usable manner.	In-Scope The prototype will provide a tool for users to prepare a report and submit it accordingly. The prototype will also improve the delivery time of the report.
9	Referral for Follow-up /Enforcement	Examples of follow-up actions include: issuing a letter to the company; informing other inspecting bodies of the findings and observations; planning a follow-up inspection; writing notices, and possibly initiating a criminal or civil action to induce compliance.	Out-of-Scope Post-inspection activities are beyond of the scope of this research.
10	Appearance as a Witness	The inspector may be called as a witness if civil or criminal enforcement actions are taken.	Out-of-Scope Post-inspection activities are beyond of the scope of this research.

As for the technological based surveillance for the purpose of environmental quality monitoring (measurement) on construction sites, this research will only focus on the most risky environmental impacts on construction sites in Malaysia by referring to the recent study by Zolfagharian et al. (2012): ‘Noise Pollution’ and ‘Dust Generation by Construction Machinery’. These two pollutions can be measured through Noise Quality Monitoring (A continuous A-weighted sound pressure level) and Air Quality Monitoring (Particulate Matter).

As regards environmental surveillance in Malaysia, it was confirmed through the interviews with the experts that traditional physical inspections are still being implemented. This means that all the experts conduct environmental inspections by physically visiting the construction sites and performing manual observation of the activities that may harm the environment, as well as observing the environmental mitigation measures that been put in place on construction sites.



Although the use of information and communication technology (ICT) has several advantages, its use among players in the construction industry, especially in Malaysia, is still low. The interviews with the experts revealed that they still rely on traditional communication tools (e.g. letters, e-mails, faxes and phones), on a conventional camera for taking photographs to provide evidence of non-compliance, and on paper-based documents (e.g. paper form checklists, plans and manuals) for taking notes and references whilst performing environmental inspections. They also practice conventional environmental quality monitoring whereby samples are physically taken up in the field, or acquired through the data logger, and then, subsequently, undergo laboratory analysis and/or the sampled data in the data logger is uploaded into the system (by using a diskette or any other temporary data storage devices) before an analysis to be carried out.

In terms of reporting, all the experts implemented manual reporting and record keeping processes (e.g. paper-based reporting and filing cabinets) except for EXMAL01. EXMAL01 told that her organisation practices the use of a web-based system for reporting purposes. All the findings from the site visits are regularly updated in the system. However, she admitted that their system has constraints because the system was specifically built for a desktop computer and, therefore, the system does not have the ability to take data in the field or convey information instantly from the site to the responsible party.

Other than the example given above, the use of ICT amongst the experts in this research was confined to the use of word processing software (e.g. Microsoft Word, Lotus Word, Microsoft Excel, etc.) for the preparation of inspection reports and the use of emails and an intranet for communication and the sharing of information and documents. Through these approaches, at least a minimum of 12 hours is required (including the provision of approximately 1 hour for opening and closing conference of each inspection) to prepare

and submit a report, and obtain environmental quality data respectively. Table 5-3 shows the required time period for the experts to prepare and submit a report, and obtain environmental quality monitoring data under the current approaches.

Table 5-3 The Required Time Period for Environmental Surveillance

Activities & Experts	Time Spent
Environmental Inspection	
EXMAL01	72hours
EXMAL02	24 hours
EXMAL03	12 hours
EXMAL04	24 hours
Environmental Quality Monitoring	
EXMAL01	14 days
EXMAL02	7 days
EXMAL03	½ day
EXMAL04	1 day

All the experts were also asked about the features that they would like to have if they could have one new “killer” ICT application designed to assist them in managing their environmental surveillance activities. Taking into consideration the weaknesses of the existing reporting system, EXMAL01 wanted to have a mobile application that was flexible and could link to the existing system. The mobile application should have a dashboard to show the weather conditions on the sites and should also have the ability to send an alert in any situation where the environmental quality data exceeded the threshold. In line with EXMAL01, EXMAL02 was also looking forward to any mobile application that is able to send an alert for non-compliance and show weather conditions. EXMAL02 and EXMAL03, however, were concerned about the ability of the application to assist them in preparing a report whilst carrying out an observation at

site. For them the application must be able to capture a photograph of non-compliance and submit the report to the responsible parties within a short time period.

5.2.2. USER NEEDS IDENTIFICATION

Section C of the interview questions questioned the experts concerning the information and services required by them in managing their environmental surveillance activities. Section C also asked concerning the key information that they require so that they are able to deliver their tasks more effectively. In addition, they were asked about the information and external services that they would like to be delivered to them in real-time. Last but not least, as the mobile web is heavily associated with social networking media like Facebook and Twitter, they were asked to give their opinion on the use of social networking media for conveying messages on environmental status.

With regard to the results, in order to provide a focused approach to the dissemination of the information from the four detailed semi-structured interviews, the information is processed using nVivo 10 and the results coded to relevant nodes to develop underlying themes. These nodes were subsequently used to create specific word clouds that can be discussed with greater certainty, because the frequency of the words is in direct relation to the main theme. Word clouds provide a graphic illustration and give greater prominence to phrases that appear more frequently in the interviews, thus aiding in the dissemination of information into a more concise and meaningful script. On scrutinising the four interviews in unison, Figure 5-2 depicts the most prominent words and phrases discussed throughout the semi-structured interviews.



Figure 5-2 Information and Services Requirements for Environmental Surveillance

With regards to the communication medium for conveying messages on environmental status, not all the experts were in agreement as to the use of social networking media like Facebook or Twitter for such a purpose. This was due to the reason that environmental data should be contained within the organisation and because some of data are classified as confidential. Additionally, the use of company assets for accessing social networking media like Facebook or Twitter during their working office hours is prohibited.

As the initial response to the idea was positive, this research requires undertaking further study as the design research moved forward. Furthermore, the main challenge of this research was to study stakeholder reactions to such a system that does not yet exist. And therefore, it was essential to find out whether the positive responses were, for instance, solely feedback to the novel idea of such applications or perhaps a sign of interest in usage which may actually sustain this kind of mobile web. For these reasons, a scenario-based design approach was effective in engaging the experts in a design process by helping the researcher to present specific stories of use which increased their interest and also obtained a buy-in from them.

Scenarios are stories used to describe how a particular user completes a task or behaves in a given situation. They provide a setting, actors, objectives or goals, a sequence of events and close with a result (Baxter and Courage, 2005, Muller, 2003). Because the development of a scenario can be time-consuming, the focus should be on the primary

tasks that users will encounter and then move to secondary tasks, if time permits (Baxter and Courage, 2005). Scenarios normally include descriptions of an individual user; the task or situation; the user's desired outcome/goal for that task; procedure and task flow information; a time interval, and the envisioned features/functionality the user will need/use.

To make scenarios more consistent with each other and more complete, McInerney (2003) has provided a template that contains the required information for each scenario. It includes:

- Title. This provides a general description of the situation.
- Situation/task. This describes the initial situation, the challenge facing the user and the user's goal.
- Method to address the situation. There are many ways in which a user could accomplish a given task and this needs to be explained in the form of a bullet list or a task flow diagram.
- Execution path. This discusses the specific features, or technologies, used in performing the tasks and describes how a user's goal is reached.

Because Section D used scenarios, it was slightly different when compared to other the sections. In Section D, the respondents were given the scenarios and were asked to figure out what features of the proposed prototype that were required in order to perform each scenario. After all respondents give their views on the features that should be available on the prototype, they were given a presentation and detail explanation of the low-fidelity prototypes that have been prepared beforehand. The experts then were asked a series of questions designed to assess whether the proposed prototype contains the features that were in line with their views before or vice versa. And most importantly, the experts were asked whether the intended prototype is suitable to be used for environmental surveillance and to confirm the features and functions of the mobile web that they required.

For this research, four scenarios were developed and were discussed with the interviewees after the interview. In all of the scenarios, the experts were told to imagine that they were using a smartphone to browse the mobile web while experiencing these scenarios at a construction site. Basically, the scenarios were representative of a task

which the researcher believed the typical environmental inspector might perform on the website based on the findings in the literature review in the Chapter 2.

As been discussed in the Chapter 2, key for a successful site visit is the familiarity of the inspector with the current situation, the activities and processes, the history and other aspects of the site to be visited (European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL), 1999). Such knowledge would assist the inspector in being able to assign priorities and producing an inspection plan. Thus, in Scenario 1, the interviewees were exposed to a scenario where they needed to carry out an environmental inspection on a selected construction site for the first time and, therefore, they needed to find the relevant environmentally sensitive receptors at the said construction site. Subsequently, they were asked to figure out the features of the proposed prototype that were required so that they managed to perform the task in Scenario 1. Once the feedbacks on the features were obtained from the interviewees, they were then shown some images of screens on papers to represent the proposed layout of the prototype mobile web that allowed them to identify the environmentally sensitive receptors, and were also told about the sharing features on the prototype that allowed them to review the previous inspection reports so that they could obtain all the relevant information needed to set the inspection priorities. In addition to that, they were told that the prototype was capable of providing them with Google Maps with tagging that showed the environmentally sensitive receptors in that particular construction project. The interviewees were given an opportunity to propose any additional features or omitting the existing features.

As for the Scenario 2, literature review as well as a thorough review of commercial mobile application tools had shown that the mobile web or application is suitable to become a tool for inspection. Moe et al. (2004) for example, who has developed a mobile application for field data collection work employed in a utility industry were managed to get a buy-in from their respondents. Majority of their respondents found that their prototype was easy to use and they keen to use the application in place of paper sourcing template that they are currently using. Therefore, in the Scenario 2, the interviewees were told to imagine that they had spotted that oil containers were placed on bare ground and that oil spill was spotted on the ground. Therefore, they had to imagine that they had to take a photo of this non-compliance as evidence by using the smartphone. Then by browsing the ENSOCS mobile web through the Smartphone, they

had to put this finding onto the Web, attach the photo, provide other relevant information to support this finding, submit the report, and share the findings on the Twitter. Similar as approach as in Scenario 1, once the interviewer obtained their feedbacks, the interviewees were shown some images of screens on papers to represent the proposed digital inspection checklist which was to be embedded into the ENSOCS mobile web. They were also told about the detailed contents of the checklist and the sharing of features on the prototype that allowed them to capitalise upon the technology of the smartphone itself (e.g. take a photograph and upload it into the system, auto-detection of the coordinates, etc.). Again, the interviewees had a chance to add or omit the features.

The literature review suggests that training is an important factor throughout implementation of EMS, understanding that it may make a difference in attitude and behaviour as well as enhancing the knowledge among managers and employees (Daily and Huang, 2001, Sammalisto and Brorson, 2008). Meanwhile, Ooshaksaraie et al. (2011) suggest that the Web creates an opportunity for the development of an exclusive Knowledge Base which promotes knowledge sharing and junior environmental staff, in particular, for their on-job training. Thus, in reflecting this, Scenario 3 has been prepared. In Scenario 3, they were told that they should imagine themselves as a junior environmental officer and were using the prototype to find out the best practice for sedimentation control and to find the important areas upon which to focus during the site inspection particularly as regards sedimentation control. After all interviewees give their views on the features that should be available on the prototype, the proposed layout showing the best environmental practices as brought up on the ENSOCS mobile web were then presented to the them. The interviewees were also told that the prototype was capable of containing and displaying environmental guidelines. This would create a Knowledge Base System within the website, hence contributing to the development of environmental management knowledge amongst the users. The interviewees then were asked a series of questions designed to assess whether the proposed prototype contains the features that were in line with their views before or vice versa.

In terms of environmental communication in the construction projects, Gluch and Räsänen (2009) in their research found that project meetings is one of the facilitating tools that being used to advance environmental performance. And of course, relevant environmental information is to be furnished prior to/during any project meeting, and one of it is the status of the environmental checking and corrective action(s). Therefore, in Scenario 4, the experts were exposed to a scenario where they needed to pretend that they were attending an environmental meeting at a site office and were required to update their management on the status of the environmental checking and corrective action(s). The interviewees had a chance to figure out the features that should be available on the prototype so that they managed to perform the task in Scenario 4. Once the interviewer obtained their feedbacks, they were then shown some images of screens on papers to represent the proposed layout of the prototype mobile web showing the proposed web pages containing the real-time environmental quality monitoring data and previous inspection reports. They were also told that the prototype was capable of displaying the status of environmental quality monitoring data in real-time and also could display the previous inspection reports. Such availability can enhance the real-time visibility of the status of the environmental checking and the corrective status of the projects and thus allow accurate judgement and effective reporting in the Environmental Checking and Corrective status. Similar as approach as in previous scenarios, the interviewees were given an opportunity to propose any additional features or omitting the existing features.



Figure 5-3 Functions and Features of the Mobile Web

5.2.3. LOW-FIDELITY PROTOTYPE DEVELOPMENT

In this research, a prototyping approach was undertaken with the purpose of clarifying the requirements and developing the functional specifications as well as evaluating the design issues of the user-interface (e.g. layout, colours and icon). The initial stage included the development of paper-based prototypes as low-fidelity prototypes.

Paper-based prototypes were chosen as low-fidelity prototypes due to the fact that paper prototyping encourages quick externalization of design ideas at a minimum cost. Paper-based prototyping allows many alternatives to be produced and tested early on in the design process. Designers can iterate on a design many times before committing to an implementation. The evaluation(s) will give more emphasis to macro-level concerns, for example, primary interface screens and overall interaction metaphors (issues which have to be addressed immediately) and users, along with designers, are more willing to provide substantive critiques of the design because it presents itself as rough and informal (Sharp et al., 2011, Bailey et al., 2008, Rudd et al., 1996).

However, unlike conventional hand sketches of screens and sticky notes to represent results from user interaction, this research opted to design the user interface by using computer software. This was because it aimed at providing the most realistic look for the proposed user interfaces of the mobile web. Realizing that the user interface is one of the main challenges for designing mobile applications, as it determines how easily the users can make the programme do what they want, recommendations from others on designing the user-interface were considered. Nielsen and Molich (1990a), for example, suggested that the design should be simple, clear and address the user tasks. Whereas The World Wide Web Consortium (W3C) in “Mobile Web Best Practices 1.0” specifies that, for delivering Web content to mobile devices, the designer should be aware of device limitation, should optimize the navigation and should choose the right graphics and colours as they have to design user interfaces which are small but user-friendly and suitable for all types of devices (Rabin and McCathieNevile, 2008).

Taking on board these recommendations, the images of 320x480 pixels (which are equivalent to the screen size of an Apple iPhone) were designed in Adobe Photoshop CS6 by using the intended web colours and background, buttons, text forms, scroll down bar etc. Screens and contents were designed and implemented based on the core functionalities of an application. There were some screens that were not available due to

their functions being less important compared to others. These categories were identified according to the major focus of the developed prototype application (discussed in the previous chapter). The coloured images were then printed out and presented to the experts during the discussion of the web scenarios.

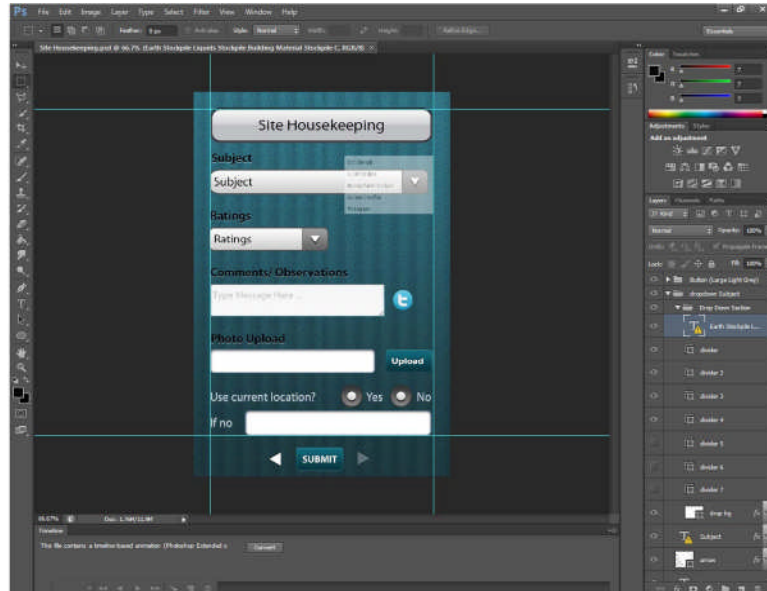


Figure 5-4 Designing of the Web Layout in Adobe Photoshop CS6

As described earlier, four domain experts were invited to comment and give feedback regarding the screen layout, colours and interactions while confirming the user requirements. Based on this feedback, the proof of concept prototypes were refined and redesigned before being tested in the Prototype Demonstration and Evaluation Stage by Environmental Management personnel on construction sites in three different case studies, two in Malaysia and one in the United Kingdom. The discussion about the demonstration and evaluation of the prototype system and the results will be covered in the Chapter 7.

5.2.4. ENVISIONING AND EVALUATION INTERVIEW

As both Kyng (1995) and Nielsen and Hackos (1993) believe in prototypes and mock-ups which are more concrete and ready for hands-on exploration (rather than traditional representations such as requirements' specifications to gather user feedback), the images of screens on papers to represent the proposed mobile web layout were used in this research as a low-fidelity prototype. However, taking note from the study of Kujala et al. (2001) that most users tend to complain about the interface details but not about the basic structure or functionality of the system during the presentation of a prototype, this research opted to combine the presentation of the low-fidelity prototype with a discussion on the scenarios, as was discussed earlier in the Section 5.2.2.

5.2.5. REQUIREMENTS SPECIFICATION

Overall the domain experts were in agreement that the proposed prototype is appropriate enough to be used for environmental surveillance. Based on the semi-structured interviews, the scenario analysis and the evaluation of the low-fidelity prototype by the domain experts, the following user needs for an environmental surveillance system were identified (see Table 5-4).

Table 5-4 Requirements Specification for ENSOCS

ID.	Identified needs and problems	Validation Method(s)	Brief description	Derived user requirements
Functional Requirements				
F1	Environmental requirements/approval conditions	Semi-structured interviews	Environmental surveillance is carried out to ensure compliance against the stated approval conditions.	Environmental requirements/approval conditions should be made available as a part of project information.
F2	Surrounding environmentally	Scenario	Information about	The system should be able to provide

<p>sensitive areas</p>	<p>analysis</p>	<p>surrounding areas and activities would help in the process of setting the priorities in environmental surveillance. For example, information about environmentally sensitive receptors would indicate an area of importance that needs to be highlighted during the surveillance.</p>	<p>information about the sensitive receptors surrounding the project area.</p>
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<p>F3 Access to project and contractors' information</p>	<p>Semi-structured interviews</p>	<p>Information pertaining to the project location and descriptions as well as the relevant contacts is important for site familiarization and</p>	<p>The system should be able to provide project and contractors' information to the users.</p>
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communication.

F4	Tools/equipment for inspection and measurement	Scenario analysis	Paper-based checklists and notes are the main instrument for environmental walk-through inspections; additionally traditional grab sampling methods for environmental monitoring are currently being used. The data can only be updated when the officers return to the office. It is time consuming and labour intensive.	Environmental surveillance data for both walk-through inspections and environmental monitoring captured from a site should be communicated in real-time up the information chain.
F5	Photograph of incidents/non-compliances	Scenario analysis	Photographs are one source of evidence to show environmental non-compliance.	The system should enable a photograph(s) to be taken using the Smartphone and upload it into the ENSOCS.

Currently, inspectors are using a conventional camera to take a photograph(s) which they need to carry along with them and then upload into a computer at a later stage.

F6	Need for EQM real-time data	Scenario analysis	The time required to obtain environmental monitoring data under current approaches may take a minimum of ½ day up to maximum 14 days. This discourages immediate action against non-compliance.	Deployment of technological based surveillance and real-time data streaming are needed.
F7	Alert on any occurrence of non-compliance	Semi-structured interviews	Alert for each measurement reading exceeding the	Ability to send an alert to the users in the event of exceeding the

threshold allows threshold.
 for immediate
 action. Under
 current
 approaches,
 sample results
 are only ready
 at least 12 hours
 after the
 fieldwork
 sampling.

F8	Services (community news, weather information, traffic information)	Evaluation of low-fidelity prototype	The effectiveness of environmental mitigations is closely linked to weather conditions and human activities (see Table 2-2). For example, there is a high probability of dust pollution occurring during the dry season and in the case of heavy traffic, whereas a siltation problem might	The system should include other services such as weather information, traffic updates and Air Pollution Index (API) as value-added services for the mobile web system.
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occur during the rainy season. For these reasons, the system should be capable of providing value-added services (that include community news, weather and traffic information) to let the inspectors have knowledge of the on-going situation on the construction site so that they can come up with informed decisions.

F9	System to support continuous learning.	Scenario analysis	The prevention of, and the resolution of, impacts and unconfirmed practices which are derived from the	The system should provide information on environmental management best practices as a part of the contents.
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practical experience of experts and professionals in the field should be shared, especially with junior environmental staff as part of their on-job training.

Non-Functional Requirements

NF1	Effective communication between parties involved in the environmental management of the project.	Semi-structured interviews	Current approaches use paper-based documentation. A long period is required for the authorities to receive, and take action on, the report.	Environmental monitoring data captured from a site should be displayed on the ENSOCS and any latest inspection report will be emailed to the respective parties immediately upon completion.
NF2	Access information when needed (especially when out of the project office)	Scenario analysis	Some organisations use intranet systems (system works on a private network) or even implement paper-based	The system should be designed as a web-based system that will be accessible via mobile devices and internet-ready

			documentation and manual record keeping. Accessing and updating data can be difficult, especially when the person is out of the office.	desktop computers.
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NF3	Ease of integration with other applications	Semi-structured interviews	Interoperability with other applications	The technology used should be interoperable and able to integrate well with existing web systems in the market. The system should also be scalable so that it can be iteratively improved.
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NF4	Portability	Semi-structured interviews	The traditional paper based methods have some drawbacks as they are certainly challenging, time consuming, labour-intensive, etc. The ability of the mobile web to provide a digital	The system must support the data requirements of both fixed and mobile network clients.
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checklist and to integrate sensory technologies as well as the features of the mobile devices themselves would improve field data collection.

NF5 User-friendly system	Evaluation of low-fidelity prototype	<p>Some of the environmental managers and officers are senior and are accustomed to using paper-based records for their day-to-day activities. Thus, they need a system that is easy to use and learn so that it is easier for them to adopt the system more effectively. A complicated system would create resistance to change.</p>	<p>The system should offer a very clear and straightforward interface and include consideration of the limited screen size, the input and output capabilities and the limitations of a mobile device.</p>
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5.3. FUNCTIONAL SPECIFICATIONS

For the purpose of understanding, as well as representing the problems raised by the users, these requirement specifications have been translated into the conceptual model. Johnson and Henderson (2002) describe a conceptual model as an idealized view of how a system is organized and operates. It includes the objects of the system, their relationships and control structures and the mechanism by which users accomplish the tasks the system is intended to support. They also argue that a designer that designs a user interface without using a conceptual model are much more likely to develop a product or service that seems arbitrary, incoherent and overly complex, not to mention heavily laden with computer-isms. Therefore, a conceptual model permits a developer to formalise the knowledge of the application in a high-level, platform-independent and formal way (Brambilla, 2003).

The conceptual model shown in Figure 5-5 presents the data flow between a user and the ENSOCS application. The user in the outer box of the diagram is the important component of the system. The numbered boxes (from 1 to 8) are the functions of the system (e.g. Login to ENSOCS) while the boxes with numbering from D1 to D19 are the items included in the class diagram (e.g. D1 – Contact Detail). In the following sections, the conceptual model provides the guidelines for the development of the functional specifications.

Concurrently, the potential functions of the system also have been finalised. Table 5-5 presents a list of the functions that the system will be required to perform and briefly describes the justification for the selection of the functions for the Environmental Surveillance on Construction Sites (ENSOCS) mobile web system.

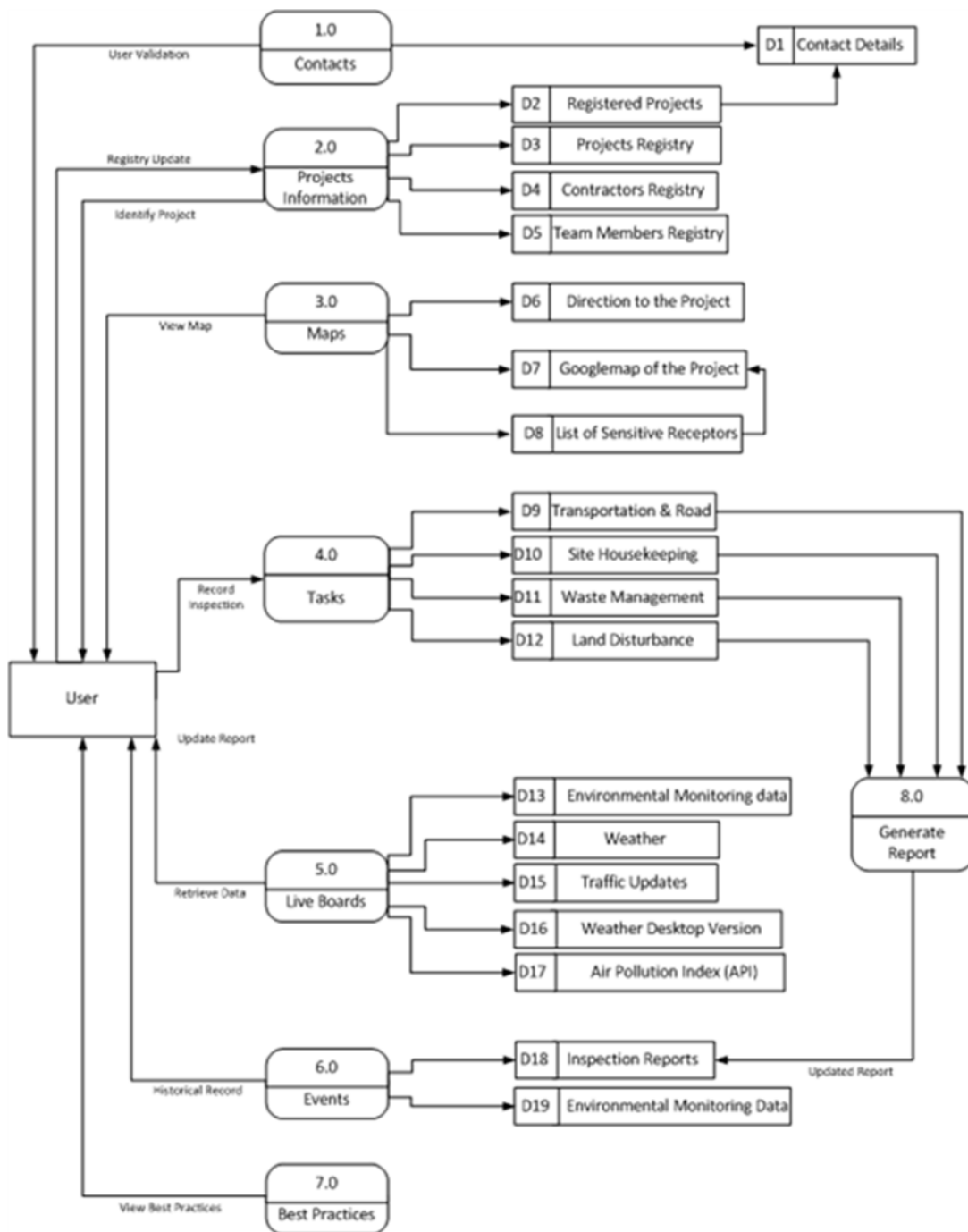


Figure 5-5 The ENSOCS Application Conceptual Model

Table 5-5 Justification for the Selection of the Functions of ENSOCS

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
0	Login	Not applicable	Only an authorized user is permitted to execute all the functions available within the application.	Information pertaining to the environmental management of a construction project is confidential. Thus, using a login page with a user ID and password is a simple and quick solution enabling restrictive access to files or directory structures of web sites which contain sensitive information (Boronczyk et al., 2009).
1.0	Contacts	F3	Providing the contact details of the relevant parties. In addition to typical directory data (such as name, phone number and email address) the smartphone's capability to make a phone call will be capitalised through linking phone numbers with XHTML markup	The environmental management team should be able to contact anyone who may have relevant information, e.g. to assist them in obtaining administrative clearances and to make necessary arrangements if samples need to be taken (International

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
			that invokes a phone call. This would enable the user to make a phone call by one click.	Network for Environmental Compliance and Enforcement (INECE), 2009). In addition, Standard Operating Procedures (SOP) especially on an Emergency Response Plan (ERP) require that the respective parties should be informed in any case of non-compliance and emergency. In some cases, immediate telephone calls are urgently needed. Because the mobile web would enable a phone call, this feature will be incorporated into the ENSOCS system.
2.0	Project Information Dashboard	F1/F3	This function should enable the Environmental Management Team to have an instant view of the stakeholders	From the literature review, it was found that project dashboards in a mobile application were used for but

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
			of the projects and of project information as well as the progress status of the project.	<p>not limited to:</p> <ul style="list-style-type: none"> • A progress monitoring system (Kimoto et al., 2005). • Construction information management (Chen and Kamara, 2005). • Construction project and programme management (Fathi et al., 2009) <p>The above mentioned studies have shown that a project dashboard enhanced the visibility of the project as well as the stakeholder's information.</p>
3.0	Maps	F2	Google Maps to show the location of the project and directions to it, as well as showing the environmentally sensitive	Google Maps is used by 54% of the global smartphone population according to GlobalWebIndex from a

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
			receptors surrounding the project site.	survey undertaken in the month of August 2013 (Smith, 2013). This makes it the most popular mobile app. Satellite images are one of the sources of information for environmental assessment activities (Hamed and Effat, 2007, Ali et al., 2002) and Google Maps offers satellite imagery, street maps and Street View perspectives, as well as functions such as a route planner, and supports the maps being embedded on third-party websites via Google Maps API.
4.0	Tasks	F4/F5	This function should enable an environmental management team to update the system with the findings of the environmental inspection through the	Previous research (Bowden, 2005, Nourbakhsh et al., 2012, Kim et al., 2008, Cox et al., 2002, Moe et al., 2004) as well as commercial products

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
			online checklist (using web form handling). The environmental management team may use the mobile device's built-in camera to take a photograph of any non-compliance spotted on the site as evidence.	e.g. Inspection, Checklist, Audit Mobile Apps by IMEC Technologies, IForm EHS by Zerion Software and many more, as discussed in the previous chapters, have demonstrated that the use of mobile devices and mobile web/apps with online checklists have significantly improved reporting and communication in site inspections.
5.0	Live Boards	F6/F7/F8	This function should enable the Environmental Manager to have an instant view of the Air Pollution Index (API), the weather and traffic conditions. Deployment of environmental monitoring sensors would also enable the real-time streaming of data on PM ₁₀ and	Many researchers (Zúniga and Krishnamachari, 2003, Ghobakhlou et al., 2011, Santini et al., 2008, Xianfeng et al., 2010, Abraham and Pandian, 2013, Hartung et al., 2006) have implemented technological based surveillance by using wireless

ID	ENSOCs' System Functions	Functional Requirements ID	System Requirements	Rationale
			<p>noise quality monitoring on the web page.</p> <p>In addition, in the event where the reading of PM₁₀ and Sound Levels exceed the thresholds, the system will send a Short Messaging System (SMS) to the users as a Warning Alert.</p>	<p>sensor and the Web due to the ability of such systems to disseminate data within a short period of time.</p> <p>The warning alert system is acknowledged to be a good prevention mechanism. Thresholds set for abundances/magnitudes, when crossed, trigger set responses so that rapid action can be taken accordingly (Price et al., 2014). SMS is one way of alerting users via a warning alert system (Ramya and Palaniappan, 2012).</p>
6.0	Events	F6	<p>Previous records on environmental surveillance and environmental monitoring data will be available through this function.</p>	<p>The environmental management system (EMS) is a process of continual improvement by which an organization constantly reviews and</p>

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
				revises the system (Gastl, 2005, Whitelaw, 2004). Therefore, previous records are important in order to gauge performance against the mitigation measures in place.
7.0	Best Practices	F9	This function contains intelligent searching for relevant information on environmental best management practices on construction sites that is based on contextual information.	A key problem facing the construction industry is that all work is undertaken by transient project teams and, in the past, there has been no structured approach to learning from projects once they are completed (Anumba et al., 2008). The prevention of, and resolution of, impacts and unconfirmed practices which are derived from the practical experience of experts and professionals in the field together

ID	ENSOCS' System Functions	Functional Requirements ID	System Requirements	Rationale
				with rules, guidelines, best practices, etc. within an exclusive Web Knowledge Base would allow for knowledge sharing and junior environmental staff in particular would benefit from this Knowledge Base for their on-job training (Ooshaksaraie et al., 2011).
8.0	Generate Report	F4	The environmental surveillance report will be automatically generated once the user updates the system. The photograph(s) taken by using the mobile device's built-in camera can be attached to the environmental surveillance report too. Then, the users would also have an option to send it to the respective parties	Under the current traditional approach, the delivery of necessary information to the construction site or the collected data back to the office has been problematic and slow (Vilkko et al., 2008) but the mobile application will enable the user to communicate the information

ID	ENSOCs' System Functions	Functional Requirements ID	System Requirements	Rationale
			through an email.	in real-time up the information chain (Aziz et al., 2009b).

5.3.1. ASSUMPTIONS AND DEPENDENCIES

The functional specifications and the prototype system being developed are based on the following assumptions and dependencies:

a. Site Infrastructure:

The construction site, the project management office (PMO) and the company main headquarters (HQ) will have wireless LAN capabilities and be within 3G communication network coverage. However, WiMax and 4G would be preferable in future adaptations.

b. Company:

The organisation will be ready to adopt a change from traditional paper-based processes to computerised processes in daily management activities especially in their Standard Operating Procedures (SOP).

c. Personal Device:

Each user will be equipped with, as a minimum, a 3G Smartphone with a GPS receiver and WLAN capabilities.

d. Hardware:

The wireless sensor networks (sensor nodes and sensor gateways), the weather station and the database and application servers will be used and maintained by dedicated project staff.

5.4. ENSOCS ARCHITECTURE

Further to the requirements' specification as discussed in Section 5.2.4 as well as the representation of the usability problems that arose from the users through the conceptual model, this research continued with the development of the system model or the software architecture for the design of the Environmental Surveillance on Construction Sites (ENSOCS) mobile web system. This system architecture is important as the starting point of the software solution for the usability problems (Shaw and Garlan, 1996, Governor et al., 2009) which will be discussed in the next chapter.

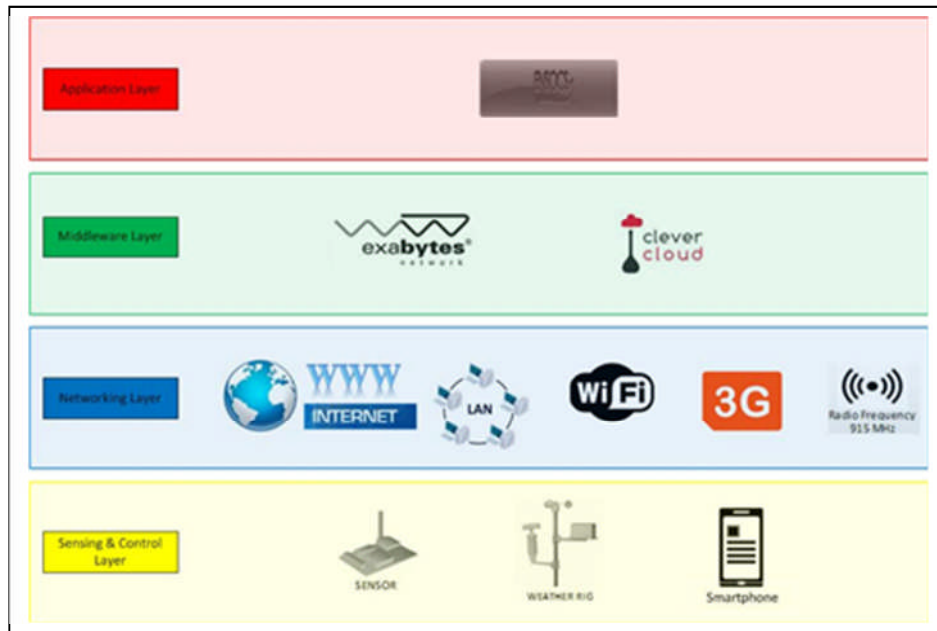


Figure 5-6 The ENSOCS Architecture

The ENSOCS architecture basically follows the common four-layer structure of the Internet of Things (IoT), as discussed in Chapter 3. It consists of the sensing and control layer, the networking layer, the middleware layer and the application layer. The details for each layer are as below:

- Sensing and Control Layer - The Telemetry Sensor for capturing the reading of PM_{10} concentrations and Noise levels and The Weather Station to obtain weather conditions' data and GPS and WLAN for the determination of the current location of the user;
- Networking Layer – Wireless Local Area Network (WLAN) and Local Area Network (LAN);
- Middleware Layer – The Server System that will process location data gathered from the built-in smartphone, the sensor data, the data input from the user and the weather data. The server will then intelligently choose 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.
- Application Layer – The Mobile Client – a mobile device that is able to deliver the inputs from the user and, at the same time, receive the location coordinates,

sensor and weather data from the built-in GPS, the wireless sensor network (WSN) and the weather station.

5.5. SUMMARY

The user requirement studies were a very important stage in this research and have been conducted thoroughly via detailed semi-structured interviews. This was to make sure that the prototype application is developed not just to prove the concept but also to reflect that the product should suit the user, rather than making the user suit the product. By adopting user-centered design (UCD), this research was able to understand the requirements of the users and the context of system use through a systematic process of requirements' development. The finding of the user requirements were then translated to the system design goals and contributed further in the formulation of the conceptual model. The user requirements, the conceptual model and the functional specifications for the prototype system presented in this chapter form the basis for the development of the prototype system described in Chapter 6.

CHAPTER 6. ENSOCS SYSTEM DEVELOPMENT

6.1. INTRODUCTION

"Prototypes" are representations of a design and features made before the final artefacts exist (Müller and Thoring, 2011). They are created to serve as materials to reflect and evaluate ideas for both the design process and design decisions (Hennipman et al., 2008, Buchenau and Suri, 2000).

Specifically for this research, two types of prototypes were developed to suit the purposes of different research stages. Low-fidelity prototypes (paper-based) were prepared in order to identify more detailed user requirements (as discussed in Chapter 5) while high-fidelity prototypes (workable mobile webpages) were developed to demonstrate the feasibility of the concepts discussed in this research with the key users involved in environmental surveillance on construction sites. This chapter presents the process of development of the ENSOCS prototype that was developed based on the system design goals set out in Chapter 5. Below is presented the overall process of development of the functional specifications of the ENSOCS web.

6.2. HIGH-FIDELITY SYSTEM DEVELOPMENT

Continuing on from the refined low-fidelity prototype, the proof of concept high-fidelity prototype system was developed based on the ENSOCS architecture described in Section 5.4. According to Sharp et al. (2011), high-fidelity prototyping is useful for selling ideas to people and for testing out technical issues. Therefore, the high-fidelity prototypes in this research were developed to demonstrate the feasibility of the concept discussed in this research to the key users involved in environmental surveillance on construction sites. As compared to the low-fidelity prototypes, the high-fidelity prototypes give an 'early feel' to the user of the application because they are able to show what the application will do, how a user will interact with it and what it will look

like. They would enable the research to discover exactly what the users want from the system, as well as what is feasible.

The ENSOCS prototype system was developed with the aim of improving environmental checking and the correction process by providing a tool for environmental enforcement offices for managing their environmental surveillance activities and enhancing their decision-making capabilities. ENSOCS is a mobile web that was specifically designed for internet browsing via a smartphone. It works together with telemetry sensors to provide real-time environmental data monitoring while the officer carries out environmental surveillance. It is intended to demonstrate the interrelationship between activities and pollution in a new way as compared to the conventional paper-based method. While maintaining the concept of a checklist, users may take a note of their environmental observations using web forms in the ENSOCS. For certain environmental aspects such as air and noise pollution, users can confirm their observational findings by referring to data transmitted by telemetry sensors in real time.

The next section presents the steps taken in the prototype design and implementation. It covers the hardware, the software and the network system required to develop the prototype. Figure 6-1 summarised the steps taken in the prototype design and implementation for this research.

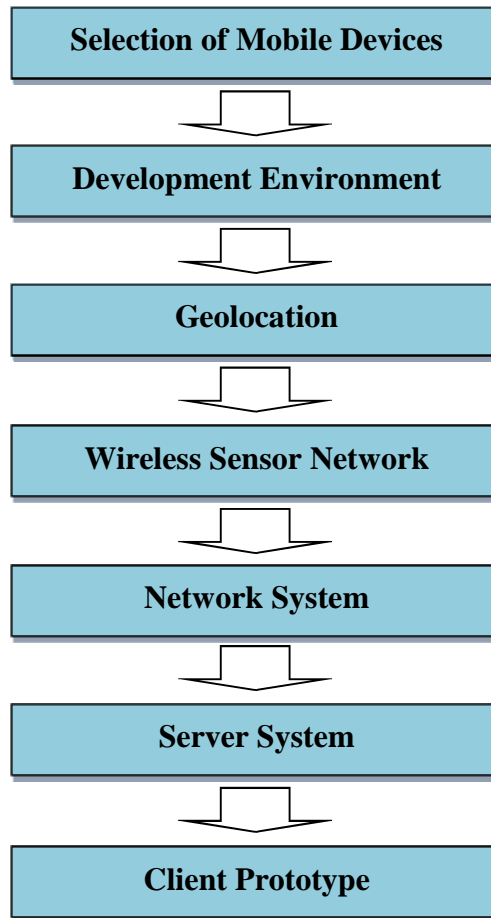


Figure 6-1 The Steps Taken in the Prototype Design and Implementation

6.2.1. SELECTION OF MOBILE DEVICES

Firtman (2010) defines mobile devices as portable, personal, staying with the user almost all the time, easy and fast to use and as having a network connection. Similarly, Livingston (2004) defines them as being 'small enough to fit comfortably into a purse, pocket or holster, so you can conveniently keep it with you at all times'.

Firtman (2010) also categorises mobile devices as including mobile phones, low-end devices, mid-end devices, high-end devices, smartphones, non-phone devices, small personal object technology (SPOTs), tablets, netbooks and notebooks. Anderson and Blackwood (2004), however, do not consider tablets, netbooks and notebooks as mobile devices due to the reason that they do not fit within Livingston's definition, and, in accordance with the IEEE's (2002) distinction between portable and mobile, they class these three items as portable.

However, in this research, a smartphone was used due to its features. A smartphone has a multi-tasking operating system, a full desktop browser, Wireless LAN (WLAN, also known as WiFi) and 3G connections, a music player and several of the following features: GPS (Global Positioning System) or A-GPS (Assisted Global Positioning System); a Digital compass; a Video-capable camera; TV out; Bluetooth; Touch support; 3D video acceleration, and an Accelerometer (Firtman, 2010). As discussed in Chapter 3, the Smartphone is better in performing phone calls, indoor shopping, SMS, MMS, proximal searches or is even best in localisation, motion detection, media capture and distribution, whereas personal computers are completely suitable for tasks like processor-intensive statistical analysis and, while tasks such as word processing, spreadsheet analysis and presentation preparation are technically possible on smartphones, it would be far easier to use a personal computer (PC) for these activities.

Furthermore, with regards to Malaysia being used for two case studies in this research, youths aged 21 to 30 in Malaysia are being prepared by the government to use the 3G smartphone through the National Broadband Initiative whereby the government has given an incentive of a RM200 rebate, starting from December 2012, to help those who cannot afford to change phones to upgrade from their old 2G phones to a basic 3G smartphone (Malaysian Communications and Multimedia Commission (MCMC), 2012). The people within this age group are currently, or soon will be, holding positions in the job market including within the construction industry. As managers within

Malaysian construction firms are already being described as being familiar with the use of computers and the internet, and are thoroughly exposed to, and interested in, adopting new technology (Jaafar et al., 2007b), this initiative hopefully will contribute significantly toward human capital in Malaysia.

Moreover, taking a view of the global perspective, recently published figures by Global Web Index Device show that four in five people worldwide now own a smartphone (Mander, 2014). The Global Web Index in the Global Web Index Device's third quarter of 2014 survey also revealed that online adults spend an average of 1.85 hours per day online via their phones while the users within the range age of 16 to 24 years spend an average of 2.84 hours per day online. Thus, undoubtedly these show that the mobile Internet sector is increasing.

In facts, due to the outlined characteristics, Pitt et al. (2011) also believe and suggest that the use of smartphones and their capabilities as integral parts of green information systems would make an important contribution toward a sustainable world. However, in the context of this research, it is more significant to have an application that can put together all their capabilities so that the user will be able to capitalise on their features at one venue. Otherwise, a user will still rely on the personal computer and use the Smartphone as a tool (as a camera, voice recorder etc.) not as embedded system. In the next section of this report, the potential application that could facilitate this objective was explored and discussed.

6.2.2. DEVELOPMENT ENVIRONMENT

Unlike desktop web development, where web developers are likely to create and test their work on the same device, mobile development generally requires creating and managing several development environments. Thus, this section will explain the process of setting up a development environment for the development of the main body of the ENSOCS prototypes. This includes development of all the components EXCEPT for the geolocation, the wireless sensor network and the weather monitoring station.

In terms of mobile web markup, PHP (an open-source server-side programming language) was used as the main programming language. PHP is particularly widely used. It is an interpretive, cross-platform, HTML scripting language, especially well-

suitable for Web development as it can be embedded into HTML pages (Rothberg, 2006). As of January 2013, PHP was being used by a remarkable 244 million sites and also demonstrated a strong installation base across web-facing computers that were part of Netcraft's Computer Counting survey (Ide, 2013). The use of PHP has speeded up the development processes as it is easy to learn (Powers, 2010).

However, PHP alone is not enough to build dynamic web sites. Therefore, other languages such as HTML5, HTML, NodeJS and C language have also been used to develop the ENSOCS prototype. As shown in Figure 6-2, the use of different programming languages is to suit different purposes. Generally, HTML5 was used for geolocation, HTML for normal webpages, NodeJS for working with a web socket in order to create a real-time web and C++ programming language for waspmote which will be discussed further in the next section.

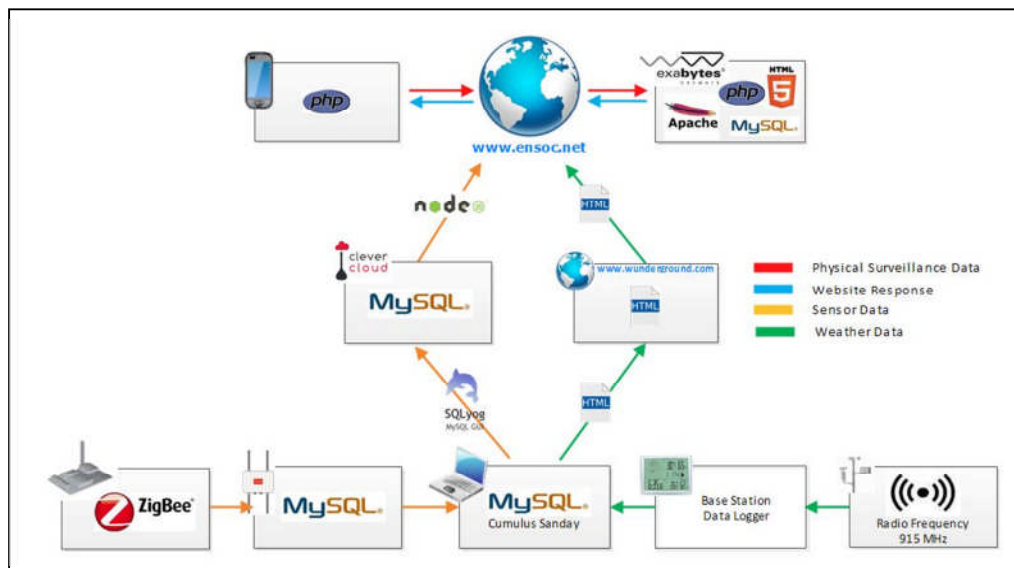


Figure 6-2 The Configuration of the ENSOCS Prototype

In order to deal with these coding markups, Adobe Dreamweaver has been used as a web tool for the development. This is because Dreamweaver (since the CS4 version), works better with mobile markup and allows one to validate against mobile web standards (Firtman, 2010). Moreover, as outlined in the Mobile Web Best Practices 1.0, it has become necessary to design online content that can appear on multiple screen sizes and which is suitable for all types of smartphone (Rabin and McCathieNevile,

2008). Adobe Dreamweaver also has a built-in emulator so that a developer has an option to test the mobile web while developing it. Myres et al. (2012) state that the emulator is easy to manage and cost-effective as it supports multiple devices. Thus, the testing of the mobile web can be conducted rapidly and easily on the desktop without the need to upload the web to the web hosting and later it can be browsed on a mobile device's web browser. For these reasons, that Adobe Dreamweaver CS6 works well with many programming languages as well as with Cascading Style Sheets (CSS) and has a built-in emulator, it means that it is the better option for this research.

Later, when the web was ready to be published, all of the web pages together were migrated to the commercial web hosting. This was undertaken by using FileZilla Client FTP Version: 3.7.3. Even though Adobe Dreamweaver has a functionality to upload web pages to a commercial web hosting, the FileZilla Client FTP Version: 3.7.3 has been used as it is highly recommended by many commercial web hostings including the web hosting for the ENSOCS.

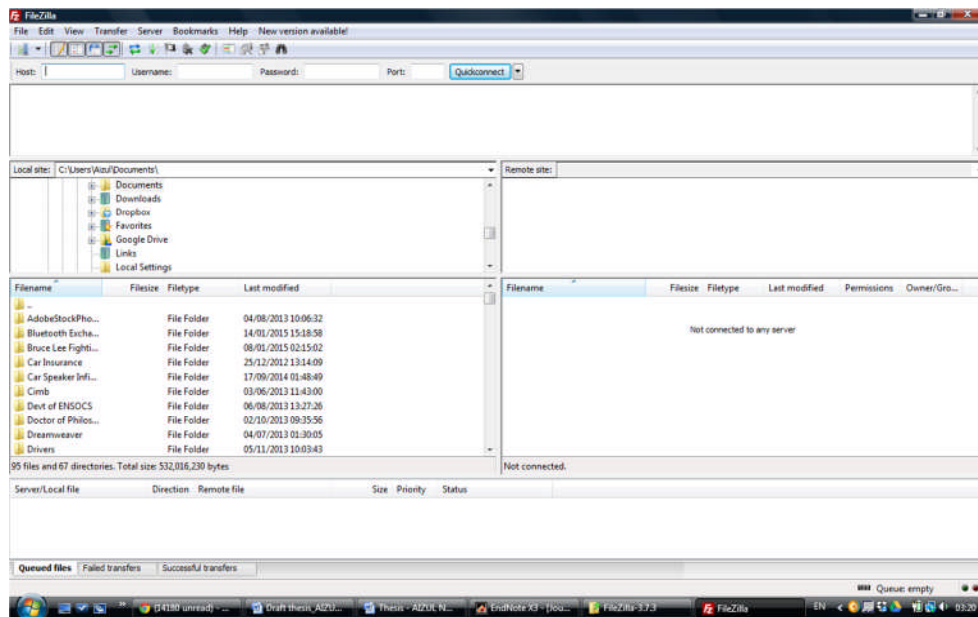


Figure 6-3 The Screenshot of FileZilla Client FTP Version 3.7.3

6.2.3. GEOLOCATION

A smartphone is a web-capable mobile device with GPS support that has changed the way people use and develop the web. Through HTML5 and Geolocation APIs, web developers now can take advantages of these capabilities to make their applications truly context sensitive and to enable the location-based service (LBS); the application can be aware of the user's location and react accordingly (Werdmuller, 2013). The features of HTML5 specifications and map APIs (Application Programming Interfaces) such as Google Maps APIs can be used to pinpoint the user's location on a map (Hu et al., 2013b, Werdmuller, 2013).

In this research, these features have been used to support the prototype's function of guiding the user with directions to the pre-identified construction sites. This would help the environmental management team to learn where a project site is by showing its location and giving the directions to it. Thus, the environmental management team would have supporting information to assist in their work planning especially for their journey planning and prioritizing the surveillance activities. In addition, these features have also been used in the digital checklist so the web browser will automatically detect and store the location of the environmental management team when they begin to fill in the checklist during the surveillance.

To execute these functions, there are four core actions that need to be supported: (1) displaying the page containing the Geolocation API code; (2) capturing the user's location; (3) storing the user's location, and (4) displaying the proposed route to the project site on Google Maps. These four core actions are supported by the Exabytes.com web server, Client-side JavaScript using jQuery, a MySQL database and the PHP scripting language. Thus, in the dedicated web pages, the smartphone will detect geolocation support, use the Geolocation API to obtain the user's coordinates, save the coordinates to MySQL via the PHP callback, and handle any errors that might occur. For directions to the project site, the proposed route will then be appear on the smartphone's web browser.

6.2.4. WIRELESS SENSOR NETWORK

As has been mentioned earlier, ENSOCS is a mobile web that works together with telemetry sensors to provide real-time environmental data monitoring whilst the inspector carries out the environmental surveillance. As one of the important parts of the prototype, a sensor node known as waspmote and a gateway known as Meshlium, manufactured and produced by Libelium, were used for this research. The waspmote comes with a Waspote Smart Cities sensor board, a Waspote Xbee 802.15.4 PRO SMA 5 DBI, a GSM/GPRS Waspote module, a Solar Energy Kit, a dust and PM₁₀ particles' sensor (GP2Y1010AU0F), and a noise sensor (WM-61A microphone) while the Meshlium comes with a 16Gb Storage Meshlium, a Meshlium Xbee 802.15.4-PRO-3G-AP, a GPS Meshlium Module and a Solar Energy Kit (Libelium Comunicaciones Distribuidas S.L, 2015).

The waspmote for this research is capable of measuring PM₁₀ and noise level through the GP2Y1010AU0F and WM-61A sensors. Basically, the GP2Y1010AU0F is used to measure the concentration of particles in suspension in the environment in air quality control applications. It is an optical sensor whose principle of operation is based on the detection of the infrared light emitted by an ILED diode, which is reflected by the dust particles and captured by means of a phototransistor (Sparkfun, 2015). Whereas the WM-61A is an omnidirectional microphone with an almost flat response in the whole frequency range of human hearing, between 20Hz and 20kHz (Smart-Home-Products, 2015). From the characteristics shown in the specifications we can infer a noise level of 26dB±1dB SPLA approximately and a dynamic range of 79.5dB approximately (Libelium Comunicaciones Distribuidas S.L, 2013b). For this research, the Smart Cities board was supplied calibrated by Libelium to return an output in the range between 50dB SPLA and 100dB SPLA with an accuracy of ±2.5dB SPLA.

This waspmote came configured to send frames to the Meshlium through the Xbee communication protocol as well as being configured to send a Short Message Service (SMS) to the dedicated person in the event where the reading of the sensor data exceeds the threshold. However, in order to make use of these features, it is mandatory for a user to develop the codes which determine as to how the waspmote is going to capture, process and transmit the data.

Libelium has provided an Integrated Development Environment for waspmote (Waspnote IDE). This Integrated Development Environment (IDE) is used for writing the code (C language) and uploading it to waspmote. It also used to monitor serial output and for debugging. This IDE contains the Waspnote API (the API is the set of all libraries waspmote needs for compiling programmes). Libelium also has provided waspmote programming guidelines that give ideas on how to develop the code as well as a sample of simple coding. Figure 6-4 shows the Waspnote Pro IDE v4 together with the sample of the code to measure the sensor.

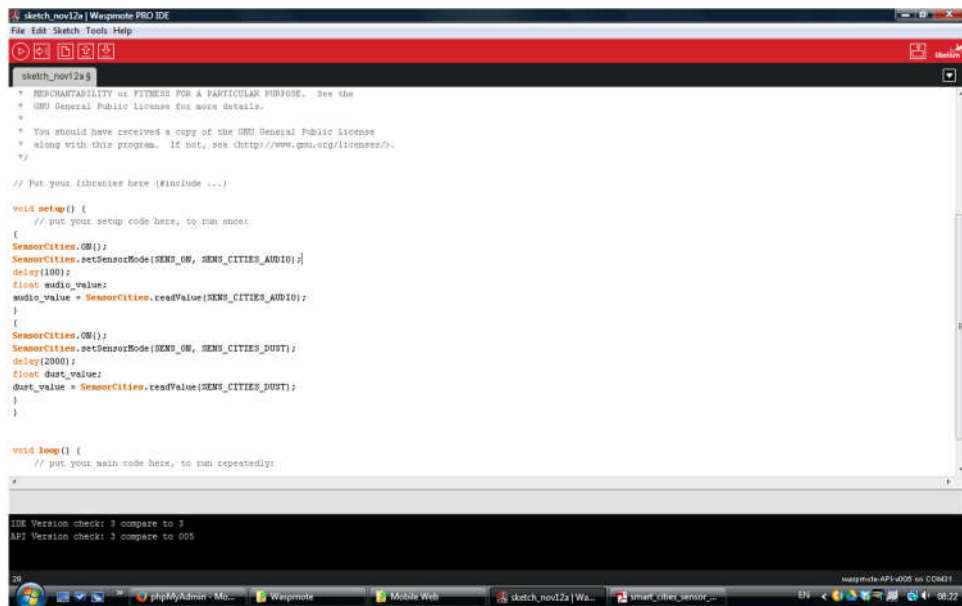


Figure 6-4 Waspnote Pro IDE v4 with the Sample Coding

This simple coding, however, is not sufficient as the ENSOCS system requires the sensor to measure at 15 minutes' intervals along with the interruptions (threshold setting) while capitalising on the functionalities of sending the SMS and of the solar energy kit. Therefore, to achieve these aims, improvements have been made in the sample coding. Many of them were modified and blended together to produce a more comprehensive new coding for this research. Figure 6-5 shows the monitor serial output on the Waspnote Pro IDE v4 displaying the sensor data by using the final developed coding.

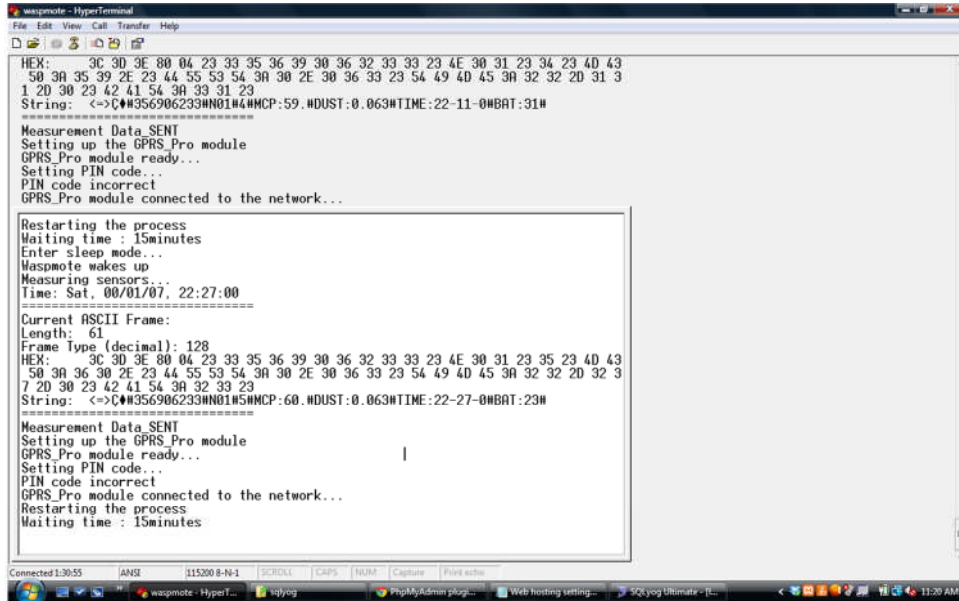


Figure 6-5 Monitor Serial Output Showing the ENSOCS Data

On the other hand, Meshlium receives the sensor data sent by Wasp mote using the ZigBee radio. Meshlium has the Manager System, a web application which allows control, quickly and easily, of the Wifi, ZigBee and 3G/GPRS configurations along with the 16GB storage options of the sensor data received in the internal MySQL database. Synchronization of this internal MySQL Database with an external MySQL Database also can be performed by using the Manager System.

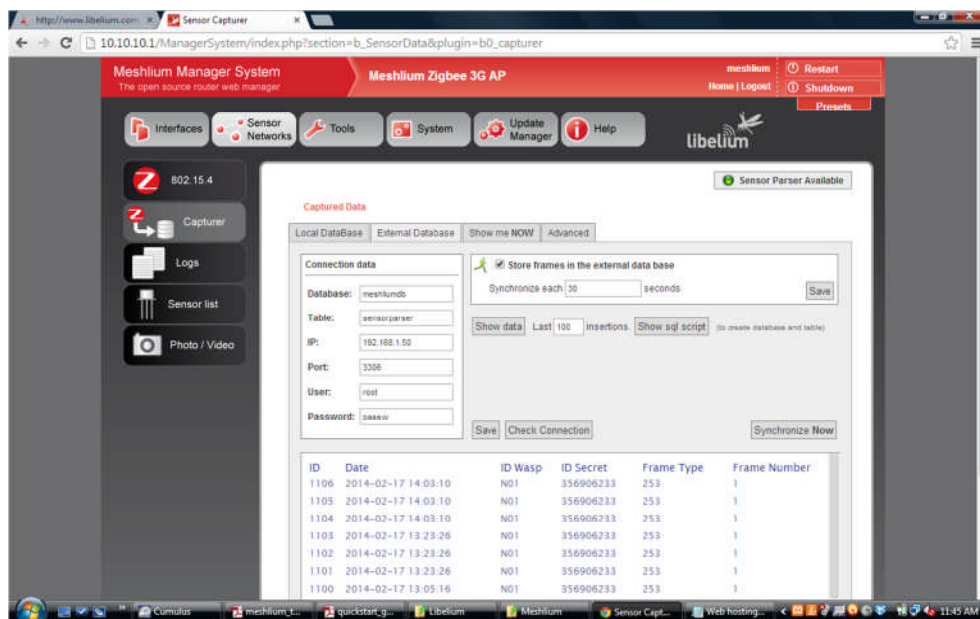


Figure 6-6 A Screenshot of the Manager System

In this case, another MySQL Database has been set up on an internet-ready laptop. The connection between this laptop and the Meshlium was established by using a local area network (LAN) cable. Then, file transfer through File Transfer Protocol (FTP) and synchronization between the Meshlium Internal MySQL Database with the MySQL database on the laptop was made by using the Manager System. Then, to make it upload into the database on the web, the laptop's MySQL database was synchronized as well with the MySQL database on the CleverCloud web hosting server by using SQLyog Enterprise computer software. These double synchronizations should not be neglected since the Meshlium Internal MySQL Database cannot be synchronized directly with any database at the web hosting server.

As mentioned earlier, the PHP programming language alone is not enough in order to build dynamic web sites and it is difficult to develop a real-time web to broadcast real-time sensor data (2013). According to Leggetter (2013), the simplest way to start building real-time apps is by using an existing solution. Thus, to broadcast the sensor data from the CleverCloud MySQL database on the web, this research opted to use the Javascript code with a combination of Node.js, socket.io, HTML5 websocket and the MySQL database. This combination works well with the CleverCloud web hosting as they are specifically designed to host the Node.js so that they can handle the above mentioned components too.

In this case, the Java code must be prepared in the GitHub prior to uploading to the web hosting server. The purpose of having the Javascript code is to broadcast the research data without having any timer on the client but only a (kind of) timer on the server. So it creates a new websocket connection with the server and fetches the data using the MySQL queries. Unlike the PHP code, this javascript code creates recursively a loop that will always update all the clients by continuously pushing data only if there are still clients connected to the application; otherwise it stops itself until at least a new client socket connection is detected. Figure 6-7 shows the Javascript code prepared in the GitHub prior to uploading to the CleverCloud Web Hosting Server.

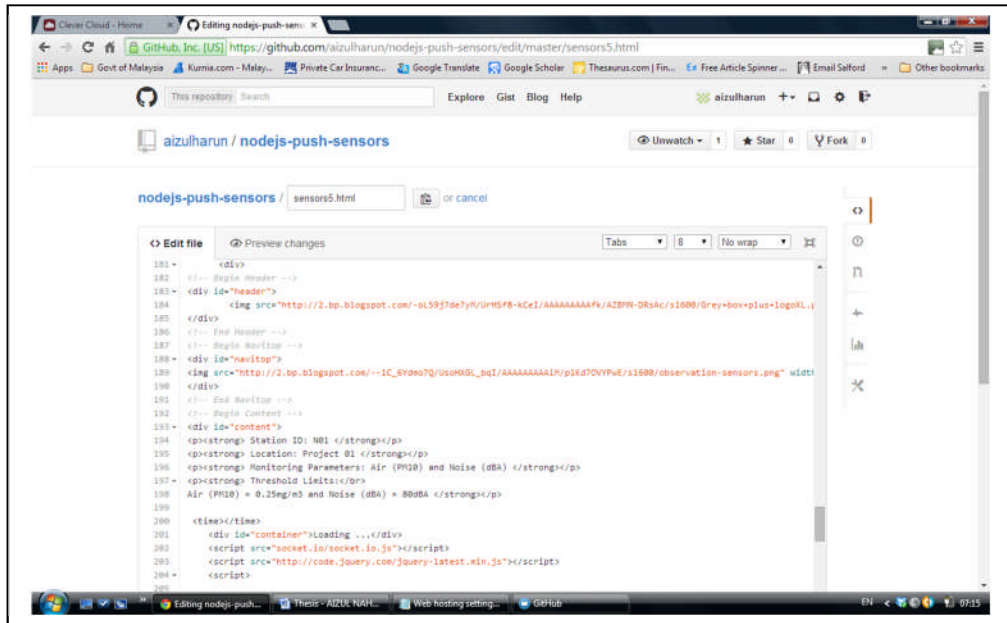


Figure 6-7 Javascript Code in the GitHub Prior to Uploading to the CleverCloud Web Hosting Server

In addition to the above, the waspmote has also been configured to enable a warning alert to be sent out through the Short Messaging System (SMS). By having this function, users will receive an SMS in the event where the reading of PM₁₀ and Noise levels exceed or nearly exceed the threshold.



Figure 6-8 Screenshot of the SMS received by the Smartphone during the trials

6.2.5. WEATHER MONITORING STATION

As a part of the ENSOCS components, a Weatherwise professional weather station (manufactured by WeatherWise Instruments) has been used to capture the weather data including wind speed and direction, rain gauge measurements and temperature. The hardware for this monitoring system contains a touch screen Weather Station. The weather rig, which is equipped with a solar powered sensor, has the advantage of being able to operate for long periods of time without a battery replacement.

Within a distance of 300 feet (without any obstacles in the open field) weather data is transmitted every 48 seconds to the Weather Station from the weather rig via the radio frequency of 915Mhz. The Weather Station is then connected to the PC by using the USB cable. Through the installation of The EasyWeather software package on the PC, the Weather Station allows the read-out of all measured and displayed time and weather data in the form of complete history data sets on the PC. Table 6-1 shows the manufacturer specifications for the weather data.

Table 6-1 The Manufacturer Specifications for the Weather Data

Nos.	Descriptions
1.	Wind Speed Measurement: 0 to 112 mph (0-160km/h) (show - if beyond range) Accuracy : ± 2.2 mph or 10% (whichever is greater)
2.	Wind Direction Measurement: 0 to 360° Accuracy : 22.5° (16 point compass)
3.	Rain Gauge Rain volume display : 0 to 394 in. (show - if beyond range) Accuracy : $\pm 10\%$
4.	Temperature Temperature range : -40°F to +149°F (-40°C to 65°C) Accuracy : $\pm 2^\circ\text{F}$

For the weather data to be displayed on the web, additional computer software (Cumulus) was required. Cumulus by Sandaysoft is a freeware programme for retrieving, storing and displaying data from an electronic Automatic Weather Station. Cumulus will store full weather records, along with daily and all-time records, and graphical data, and then automatically upload it to a web server and the website of Weather Underground. The data displayed on the website of Weather Underground then was used and customised in order to make it appear on the prototype. Here some PHP web programming language, by using Dreamweaver software, was involved.

6.2.6. NETWORK SYSTEM

This section explains the requirements imposed on the network system by the ENSOCS prototype system. As has been discussed in earlier sections, the information on the environmental aspects and impacts and on other related information for ENSOCS are derived from many different sources spread around the network. Thus, the main requirement for ENSOCS is that the network should be able to collect raw data from these sources constantly, process it and, as needed, deliver it to the smartphone as required. Actually, the details on the network systems adapted for ENSOCS and how they work within the ENSOCS architecture have been discussed indirectly in previous sections. However, Table 6-2 presents a summary of the network systems and their functions.

Table 6-2 A Summary of the Network Systems and Their Functions.

Nos.	Network Systems/ Communication Protocol	Connection	Data
1.	Wireless Local Area Network (WLAN)		
i.	WIFI 802.11b/g	<ul style="list-style-type: none"> • Smartphone - ENSOCS • Local Database - MySQL 	Observation data Sensor data (PM ₁₀ and noise levels)
ii.	GSM-GPRS-3G	<ul style="list-style-type: none"> • Smartphone - ENSOCS • Waspnote - Smartphone 	Observation data Warning Alert

Nos.	Network Systems/ Communication Protocol	Connection	Data
			(SMS)
iii.	Radio Frequencies 915Mhz	<ul style="list-style-type: none"> • Weather Rig – Weather Station 	Weather data (Wind Speed and Direction, Rain Gauge Measurements and Temperature)
iv.	ZigBEE-PRO	<ul style="list-style-type: none"> • Waspote - Sensor Gateway 	Sensor data (PM ₁₀ and noise levels)
2.	Local Area Network (LAN)		
i.	USB Cable	<ul style="list-style-type: none"> • Weather station - Local Database 	Weather data (Wind Speed and Direction, Rain Gauge Measurements and Temperature)
ii.	LAN Cable	<ul style="list-style-type: none"> • Sensor Gateway - Local Database 	Sensor data (PM ₁₀ and noise levels)

6.2.7. SERVER SYSTEM

A web online system needs a server machine host to store the web site and the server programme to deliver the web pages as well as to process and deliver their associated files like images, flash movies etc. to clients (browsers). In addition, the system also needs a database server to store all the files and data. A similar set-up is used for the ENSOCS prototype.

At the prototype development stage, XAMPP, a free and open source cross-platform web server solution stack package, was installed on the local machine (an AMD Athlon Neo MV-40 1.60GHz Notebook). The XAMPP usually includes the Apache HTTP Server, a MySQL database, and interpreters for scripts written in the PHP and Perl programming languages. Because of the availability of these components within the XAMPP, it has been used in this research as a development tool, to test the web on the computers without any access to the Internet.

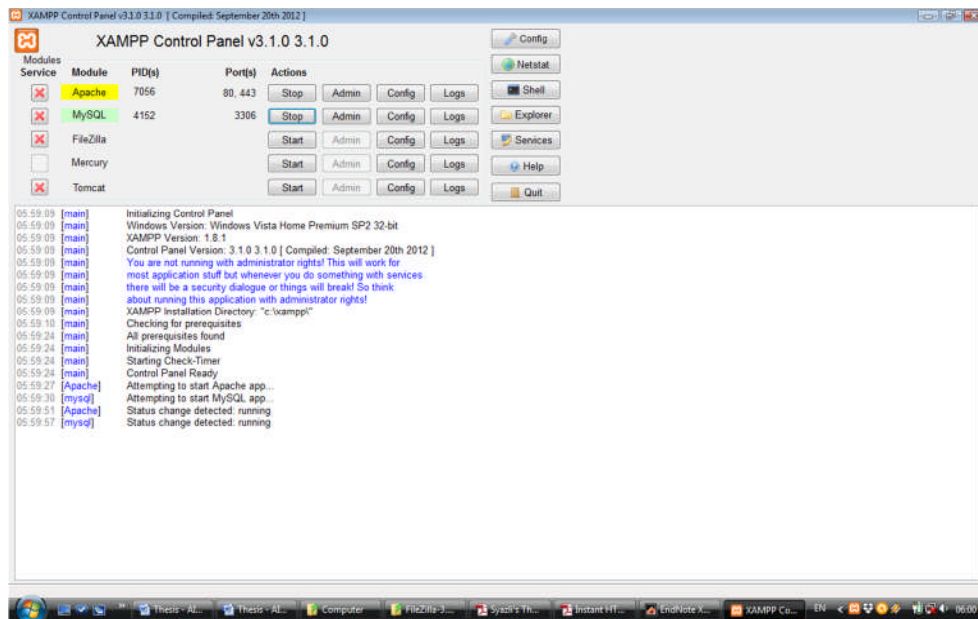


Figure 6-9 The XAMPP Control Panel v3.1.03.1.0

Later, when the web was ready to be published, all the web pages together with files and the MySQL database were migrated to the commercial web hosting. As mentioned earlier in the previous sections, two commercial web hostings were used, namely Exabytes (Malaysia) and Clever Cloud. Exabytes (Malaysia) was chosen because it supports the PHP web programming language while Clever Cloud supports the NodeJS

which is an important component for the ENSOCS web pages and facilitates the real-time monitoring data display, respectively. Furthermore, both of them are well-known web hosting and support the MySQL database, the free open-source database that works best with PHP and the ENSOCS' wireless sensor network.

6.3. CLIENT PROTOTYPE APPLICATION

This section will present the many main functions of the prototype system that was designed by combining all the components previously discussed in order to satisfy the system design objectives as identified in Chapter 5. Therefore, as shown in Table 5-5, the ENSOCS prototype mobile web system has been developed with the following features:

1. Login
2. Main Menu
3. Contacts
4. Project Information
5. Maps
6. Tasks
7. Generate Report
8. Events
9. Liveboards

6.3.1. LOGIN

The ENSOCS prototype mobile environmental management system is not open for access by the public. It is purposely built for an environmental management team, as target users, so that they will have IT tools to assist them in their day-to-day activities. Based on the user requirement studies, it was shown that such users deal with information relating to the management of the environment of a construction project which is classified as confidential.

Therefore, to limit access only to authorised users, the login page has been designed. The users have to register and create their own user ID and password. In the login page, the user ID is visible when entered but the password is kept secret (and is not displayed as it is entered). Thus registered users can then enter the ENSOCS by logging on in order to get into the main menu and execute all the functions that they want. Figure 6-10 shows the login page.

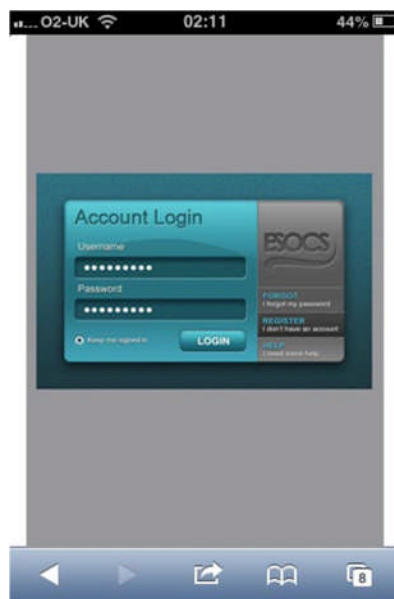


Figure 6-10 The ENSOCS Login Page

6.3.2. MAIN MENU

With the aim of providing a user-friendly prototype, the ENSOCS system was designed so that the main functions can be executed by the user clicking the icons on the main menu. As elaborated in earlier sections, the ENSOCS will come with seven (7) main functions. Thus, seven (7) icons to represent these functions were made available for the user.



Figure 6-11 The Main Menu of ENSOCS

6.3.3. CONTACTS

Contact numbers are important especially in the case of emergencies or when highly urgent environmental incidents happen at site e.g. flooding, major oil spillage and fire. Because of such possibilities, the environmental management team should have key important contact numbers ready to hand to help them react quickly in the case of such incidents occurring. Taking this on board, the ENSOCS prototype provides the contact details of relevant parties. In addition to typical directory data such as name, telephone number and email address, the smartphone's capability to make a phone call will be capitalised through linking phone numbers with a XHTML markup that invokes a phone call. This would enable the user to make a phone call by one click. A similar method as that suggested by Mehta (2008) to invoke a phone call has been used.



Figure 6-12 Phonebook of the ENSOCS Prototype

6.3.4. PROJECT INFORMATION

Project information will give an idea of the nature of the works, the scale of construction, the contractual parties involved and their progress. This enhances the understanding of the environmental management team concerning the construction project that they are going to inspect. The prototype, however, will not display actual project information but only mock-up information because the respondents in this research should remain anonymous.

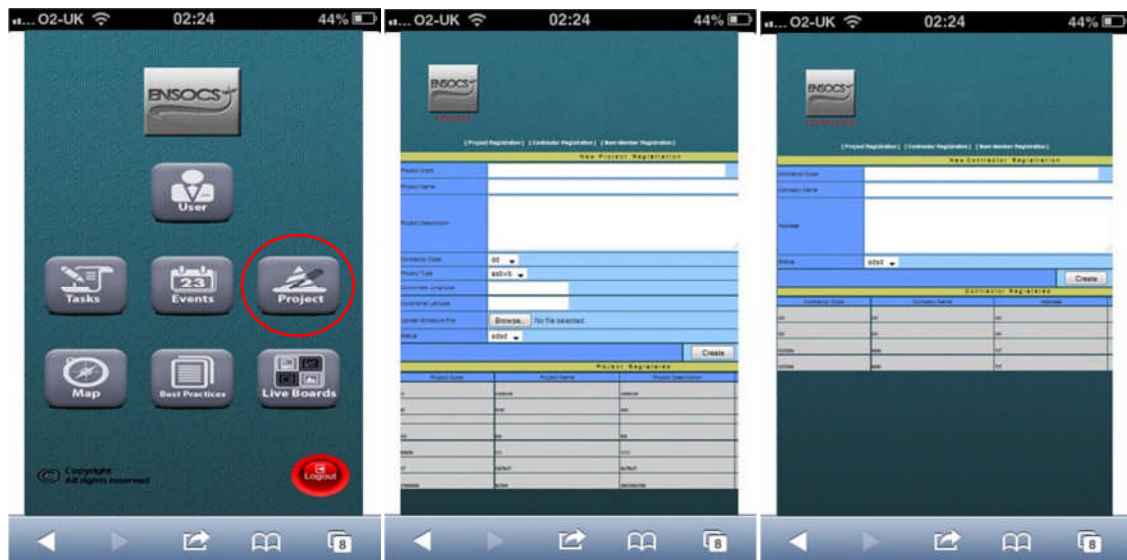


Figure 6-13 Web Page showing Project Information in ENSOCS

6.3.5. MAPS

As has been mentioned earlier, the environmental management team has to be familiar with the construction site that they are going to inspect. They have to know where the exact location of the site is and what the surrounding activities are. Thus, this function will display a Google map showing the demarcation of the construction site (via KML file) and the activities within the 3 kilometres' surrounding area. By referring to the map, the team would have an idea about the location of the project and the surrounding activities as well as the sensitive receptors within the project. Therefore, it will help the environmental management team to prioritize their focuses of inspection prior to arriving at site and will be very useful particularly for those who are newly attached to the construction sites.

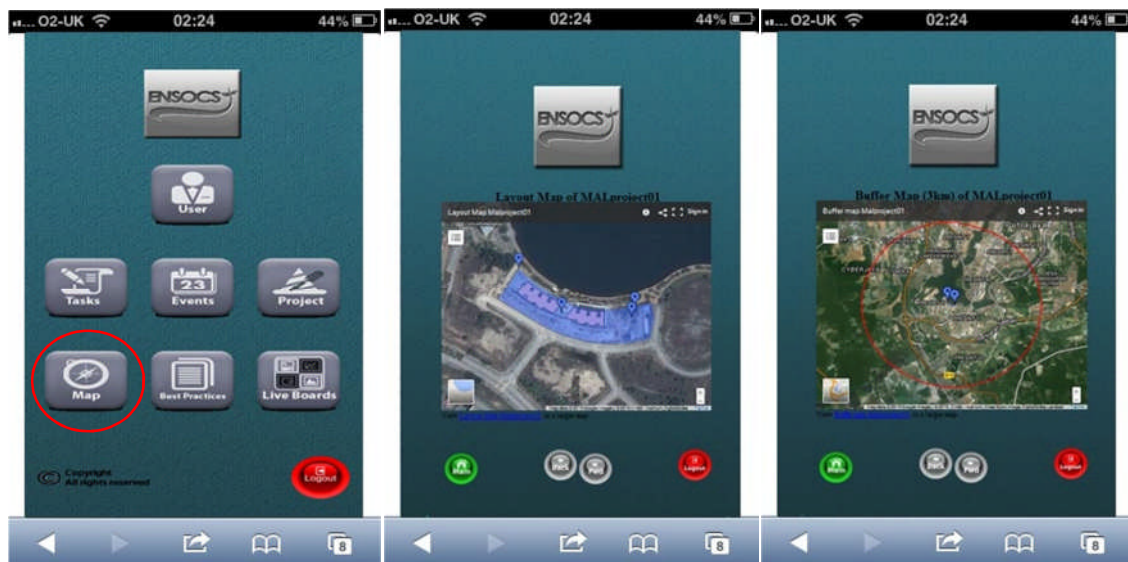


Figure 6-14 Map Features of ENSOCS

6.3.6. TASKS

One of the purposes of this application is to provide a tool for the environmental management team to manage their environmental surveillance activities on the construction sites. The ENSOCS prototype still maintains the concept of a checklist but users may take a note of their environmental observations using web forms in ENSOCS rather than using a hand-copy checklist. They can also use the camera function on the smartphone to take photograph(s) as supporting information for their observation report. This handy tool will replace the use of a paper-based checklist, pens and a conventional

camera so that the environmental management team do not have to carry too many things in their hands during the surveillance.



Figure 6-15 The Online Checklist within ENSOCS

6.3.7. GENERATE REPORT

The user requirement studies showed that a delay in reporting is one of the disadvantages of the current method of surveillance in Malaysia. Thus, this prototype will help to expedite the delivery of the surveillance report by providing features that can upload the observation report to the web and, subsequently, make it display on the prototype alongside sending an email of the summary report to the respective appropriate personnel. The recipients then would have to refer to the prototype in order to view the full report together with the photographs.

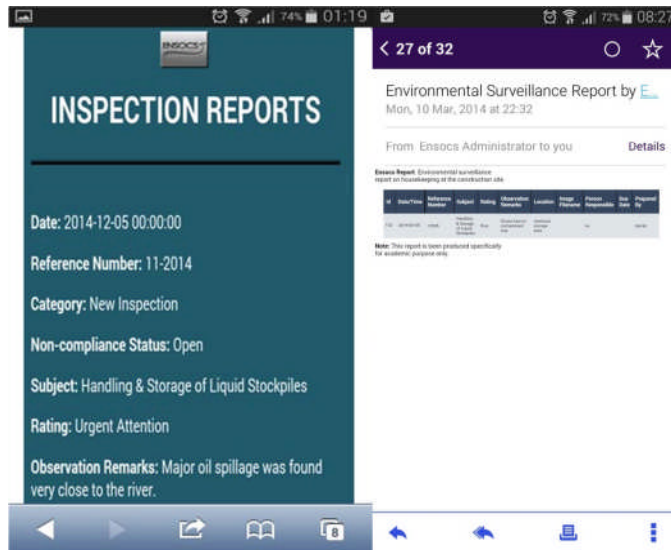


Figure 6-16 Sample of a Surveillance Report (Left: Online report; Right: Emailed report) of ENSOCS

6.3.8. EVENTS

Within this feature, all the data and information available on the previous inspections/observation reports and the environmental quality monitoring data will display on the web page of the prototype. The database server will push all this data and information to the prototype to make this happen. The name of this feature “Events” however, was found to be inappropriate during the prototype demonstration. The renaming has been made and the details will be discussed in the next chapter.



Figure 6-17 The List of Previous Reports and Monitoring Data in ENSOCS

6.3.9. LIVEBOARDS

The ENSOCS prototype system was also developed as a tool to enhance decision-making capabilities. ENSOCS works together with a wireless sensor network to provide real-time environmental data monitoring while an inspector carries out environmental surveillance. By using this function, the environmental management team can confirm their observational findings by referring to the air and noise readings transmitted by telemetry sensors in real-time rather than rely on a complaint or a long-awaited laboratory result. Therefore, action can be taken immediately in any case where the parameters' reading exceeds or nearly hits the threshold. In addition, the live boards function will also display the weather and the traffic conditions. This function would make it easier for the environmental management team to plan their work and perform some predictions of possibility issues. For example, it is highly probable that dust problems will happen during dry weather or that siltation and flooding might happen during heavy downpours. Therefore, the team can manage their resources and make them ready for any possibilities that might occur.

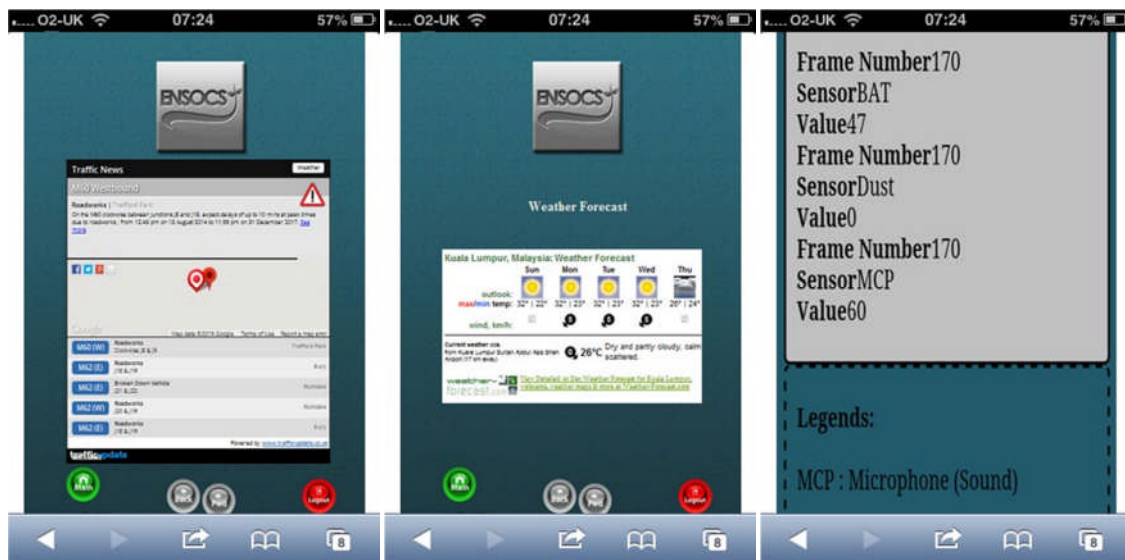


Figure 6-18 The Liveboards Features of ENSOCS

Figure 6-18 as above shows the sample of graphical user interfaces for the traffic updates (left), weather updates (center) and real-time environmental quality monitoring data (right). As for the traffic updates, the system is capable to display the traffic condition around the city of Manchester, United Kingdom sourcing from website of Traffic Update at <http://www.traffic-update.co.uk/>. The available information includes

the real-time map to show the congested roads and the related information such as estimated time delays and the description of the affected roads. Whereas for the weather updates, the weather forecast from the Met Office of United Kingdom as well as real-time data of the rain gauge, wind speed and direction which gathered from the weather station on site are made available on the system. Similarly to the real-time environmental quality monitoring data, real-time data of PM₁₀ and Noise Levels streaming from the wireless sensor networks are made available on the system through “Live Board” (system function ID 5.0) as well.

6.4. SUMMARY

This chapter has presented the prototype system that was designed and developed to satisfy the user requirements as identified in Chapter 5. Generally, the ENSOCS’ System Functions have been developed to address the functional and non-functional requirements by the users. Table 6-3 provides a checklist as evidence to show that the ENSOCS’ System Functions are fully complied with the finding or recommendation as in the User Requirements Studies.

Table 6-3 The System Compliance to the User Requirements Checklist

ID.	User Requirements	Satisfied The Requirements?		Remarks
		Yes	No	
Functional Requirements				
F1	Environmental requirements/approval conditions	√		Environmental requirements/approval conditions were made available as a part of project information through the “Project Information Dashboard” (system function

ID.	User Requirements	Satisfied The Requirements?		Remarks
		Yes	No	
				ID 2.0).
F2	Surrounding environmentally sensitive areas	√		The system now is able to provide information about the sensitive receptors surrounding the project area by capitalizing the advantages of the Google Map under the system function of “Map” (system function ID 3.0).
F3	Access to project and contractors’ information	√		The project and contractors’ information are available to the users through the “Project Information Dashboard” (system function ID 2.0) as well.
F4	Tools/equipment for inspection and measurement	√		The system function of “Task” (system function ID 4.0) was developed to address the issue of capturing and communicating the environmental surveillance data in real-time up the information chain.
F5	Photograph of incidents/non-compliances	√		The system has enabled a photograph(s) to be taken using the Smartphone and upload it into the ENSOCS as a part of system function of

ID.	User Requirements	Satisfied The Requirements?		Remarks
		Yes	No	
				“Task” (system function ID 4.0).
F6	Need for EQM real-time data	√		Real-time data streaming from the wireless sensor networks are made available on the system through “Live Board (system function ID 5.0) whereas the historical data can be achieved at the system function of “Events” (system function ID 6.0).
F7	Alert on any occurrence of non-compliance	√		The system will send an alert to the users via Short Messaging System (SMS) in the event where the reading of PM ₁₀ and Noise Levels exceeding the threshold. The data will also appear on the “Live Board” (system function ID5.0).
F8	Services (community news, weather information, traffic information)	√		The weather updates and forecast, Air Pollution Index (API) and traffic updates have become a part of the “Live Board” (system function ID5.0).
F9	System to support continuous learning.	√		A dedicated function known as “Best Practices (system

ID.	User Requirements	Satisfied The Requirements?		Remarks
		Yes	No	
				function ID 7.0) has been developed with the aims to provide information on environmental management best practices and encourage the continuous learning process.

However, it is important to note that this is not the end of the development as the full assessment of the system functions in addressing the non-functional requirements is required. Furthermore, the researcher must achieve some level of confidence that the prototype is not only technically feasible but that the concept is also acceptable to the industry. Thus, the researcher adopted an iterative approach whereby the targeted users were involved in the prototype evaluation in order to ensure that the prototype can gradually be developed to become a robust system.

Therefore, the next chapter discusses the evaluation of the prototype system and presents the results from the prototype evaluation. The evaluation is made to prove the concept, to strengthen the user requirements and to see whether the application can provide efficient information and services. The results from the evaluation and the refined prototype can be used to help in developing and applying the ENSOCS prototype to real applications.

CHAPTER 7. DEMONSTRATION AND EVALUATION OF THE PROTOTYPE SYSTEM

7.1. INTRODUCTION

This chapter presents the demonstration and the evaluation of the ENSOCS prototype application focusing on User-Centred Evaluation (UCD). UCD represents the techniques, processes, methods and procedures for designing usable products and systems. But just as important, it is a philosophy that places the user at the centre of the process.

The system needs to be tested prior to being handed over to users. Testing exercises are important because, through them, developers can raise system quality and reliability and can also find and remove errors from the system (Myers et al., 2012). Such testing would establish some degree of confidence that a programme does what it is supposed to do and does not do what it is not supposed to do. Henceforth, this is useful to help protect users from any negative impact of such a system. In addition, this testing exercise is critical in order to prove the concept and receive acceptance from practitioners in the field.

Therefore, in this research, the ENSOCS prototype application was evaluated in terms of its functionality and usability. The following section presents and discusses both issues in terms of the evaluation process, results, a discussion and refined prototypes.

7.2. FUNCTIONAL EVALUATION

In the previous chapter, the development of the prototype was carried out by using Macromedia Dreamweaver. One of the reasons for using this was due to it having a built-in emulator which is capable of providing a simple, fast, and fairly accurate testing solution. According to Firtman (2010), emulators can help us to see how our websites will be rendered on real devices and websites probably will probably not work on a real device if it do not work on an emulator. However, Firtman adds further that it does not

mean that web testing via emulators is trouble free; it is still subject to a few problems as there are several platforms that cannot be emulated. Thus, real device testing still remains mandatory.

Therefore, to ensure that the prototype will work on real devices, a few functions of the prototype were tested by using both the Macromedia Dreamweaver emulator and the real device. In order to verify a particular functionality or feature of the prototype under test, a number of Test Cases have been used. Basically, a Test Case is a document specifying a list of actions which need to be executed in order to verify a particular functionality or feature of the application under test (Singh, 2014) so that it can be checked as to whether the application behaves as expected. A test case covers all the requirements or specifications being tested, the steps involved and the expected results. The information included in a test case was:

- Test case ID;
- Description of the test case;
- Precondition(s);
- Test steps or order of execution number;
- Post condition(s), and
- Results.

In this research, the system requirements have been identified and one test case for each requirement was produced. Table 7-1 shows a sample which is the test case for the User Login. Other test cases for the other requirements are attached in Appendix 6.

Table 7-1 Test Case for User Login

Steps	Test Case ID:	TC 0.1.1.Login		
	Description:	User Login		
	Preconditions:	The test user must be set up and be granted access to the application		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	Launch the application by typing in the url www.ensocs.net in the smartphone web browser.	The webpage containing the description of the research is displayed.	Pass	
2	User enters unique id and authorization code and clicks on “login” button.	Access is granted and the user is directed to the account login page.	Pass	
3	User enters username and password and clicks on “login” button.	Access to the application is granted. The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Prototype applications were refined iteratively until all the functional evaluations achieved pass status in all the test cases (as shown in Appendix 6) before the preliminary demonstration and usability evaluation sessions were conducted. These functional evaluations have shown that the features satisfy the requirements of the applications. However, to understand how this application can be used in real construction programme management, a usability evaluation is needed.

7.3. USABILITY EVALUATION

In brief, this study puts forward the concept of mobile web usage as a tool for managing environmental surveillance activities at construction sites by members of environmental management. Because this research has adopted a user-centered design (UCD) philosophy, the prototype development must be achieved by using techniques, processes, methods and a whole life cycle of products which focus on the user. This is to reflect the fact that the product should suit the user, rather than making the user suit the product.

The unique features of mobile devices and wireless networks pose a number of significant challenges for examining usability of mobile applications, including mobile context, multimodality, connectivity, small screen size, different display resolutions, limited processing capability and power, and restrictive data entry methods.

Thus, the aims of the ENSOCS prototype demonstration are not just to validate the concept of the research but also to ensure that the prototype is well adapted for use by the users for their tasks and most importantly, to avoid any negative outcomes from the usage of this prototype by environmental officials.

Specifically, the objectives for the demonstration and evaluation were to:

- Demonstrate the concept interactively;
- Address the usability problems of the ENSOCS prototype system;
- Refine the prototype based on the evaluation.
- Demonstrate the usefulness and practicality of the ENSOCS prototype system in construction environmental surveillance;
- Explore the ease of use of the ENSOCS prototype system, and
- Identify any barriers that can be found within the implementation of the ENSOCS prototype system.

Therefore, in order to achieve the above mentioned objectives, the demonstration and evaluation of the prototype followed the sequence given in Figure 7-1.

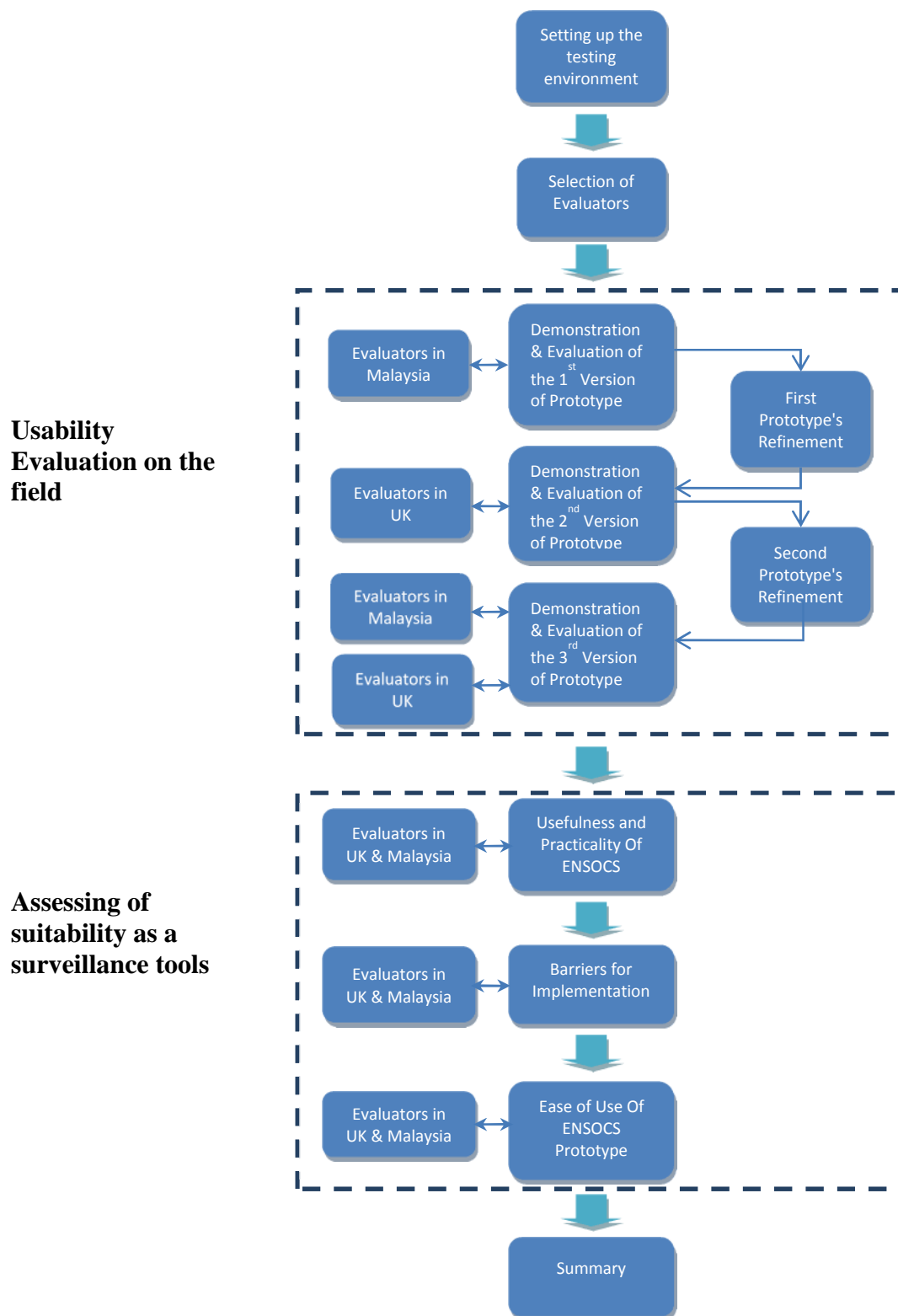


Figure 7-1 The Implementation Steps for the Demonstration and Evaluation of the ENSOCS prototype

7.3.1. TESTING ENVIRONMENT

An effective usability testing has to be able to elicit feedback from users as to whether they can use the application without (or almost without) difficulty and how they liked using the application, as well as to evaluate the levels of task performance achieved by the users (Wichansky, 2000). There are various concepts, methodologies and approaches commonly used in traditional human-computer interaction research for the usability testing of desktop applications. However, these may not be directly applicable to a mobile environment (Jones et al., 1999) due to the unique features of mobile devices such as limited bandwidth, unreliability of wireless networks, as well as changing contexts (environmental factors) (Zhang and Adipat, 2005, Kjeldskov et al., 2005). Zhang and Adipat (2005) 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. Therefore, the testing of a mobile application tested in a real environment may not work as well as it does when tested in a controlled laboratory setting.

Taking into account these issues, the ENSOCS prototype needs to be tested in a real environment, within actual on-going construction projects. However, it is important to note that a construction site is considered to be one of the most dangerous working places where there are always safety concerns for the employees. Most construction activity is difficult, dangerous, dirty, and can involve heavy machinery and scaffolding high above ground level. Most accidents that happen on construction sites are caused by a lack of training, carelessness, a failure in the interaction between the work team, workplace, equipment and materials, and not following basic safety rules while working in the site (Abdullah and Wern, 2010, Haslam et al., 2005). The most serious accidents which happen can result in injuries and death. For example in 2012, 177 accident cases on construction sites were reported in Malaysia (Department of Occupational Safety and Health Malaysia, 2013). Within this figure, almost 37.9% or 67 cases resulted in death, while 6.8% or 12 cases resulted in permanent disabilities. For such reasons, construction companies need to comply with any requirements (in addition to any security policy) that are created in order to meet federal, state and local laws. In addition, construction companies also have contractual agreements with clients that are associated with information protection and the control of the entry and exit from the project site. These limit the access to the site as well as the information associated with it.

Therefore, to find actual on-going construction sites that can be used for the case studies is difficult. Not many companies would allow outsiders to come in and explore their site or put any installation upon it for the purpose of gathering information from it. Furthermore, the requirement of this research is to walk through a site and install the wireless sensor networks on site that will capture the readings of air and noise level quality which would reflect the level of compliance as regards statutory requirements. Thus, it is not surprising that many parties voiced their concern over the future use of the data and on guaranteeing the safety of the author during his stay at the site. Because of this, only two companies in Malaysia and one in the UK expressed their willingness to allow the use of their construction sites as the case studies in this research. Details of the case studies and the rationale behind the selection are explained in the Table 7-2.

Table 7-2 Details of the Case Studies and Justifications

Case Study Id.	Location	Rationale for Selection
Case Study A	Selangor, Malaysia	Case Study A is one of the on-going mega infrastructure projects in Malaysia. The main contractor for Case Study A is a well-known public listed company in Malaysia. As an iconic development in Malaysia, they aim to put environmental protection at the highest standard.
Case Study B	Putrajaya, Malaysia	Case study B is the development of a structural building within a 2 acres' piece of land in Putrajaya. Putrajaya is the Federal Government Administrative Centre of Malaysia which is being developed based on 2 underlying concepts; Putrajaya as a garden city (sustainable development) and Putrajaya as an intelligent city. To achieve these aims, all the development must abide by stringent statutory environmental requirements such as the Environmental Quality Act 1974, the Environmental Impact Assessment Approval Conditions and Putrajaya

Case Study Id.	Location	Rationale for Selection
		Environmental Management Guidelines 1998. Thus, every contractor is required to conduct their own environmental audit, surveillance and measurements while going through enforcement programmes by the clients and the authorities.
Case Study C	Manchester, United Kingdom	The building construction company for Case Study C was one of the top ten construction companies, in terms of turnover, in the UK in 2013 (Hood, 2014). In addition, the company has put in place their own online environmental monitoring system for waste management. It is not a mobile system for environmental surveillance or quality monitoring, but at least their personnel are being exposed to the use of IT systems for environmental management.

Prior to the fieldwork and usability testing, the author was required to attend a one-day Safety Induction Course in each of the case studies as a part of the companies' requirements, even though the author has 10 years of working experience in the construction industry and possesses the accreditation of Construction Personnel under the CIDB Green Card programme (see CIDB (2012)) of the Construction Industrial Development Board of Malaysia. Upon completion of the Safety Induction Course, the access to the case studies was granted on 13th July 2013 for Case Study A, 16th July 2013 for Case Study B and 11th December 2013 for Case Study C. The permissions granted included direct engagement with nominated environmental management personnel, usage of the construction projects as case studies and installation of a wireless sensor network on the sites.

As regards the real-time environmental quality data component of the prototype, two sets of baseline environmental quality data were acquired on 13th January 2014 at 11.15am and 16th January 2014 at 2.10pm prior to the installation of the wireless sensor

networks at the Case Study C. The waspmote was temporarily put in place outside the construction's hoarding and close to the sensitive receptors. The real-time sound levels were recorded at an average of 75.67dbA on 13th January 2014 and 72.17dbA on 16th January 2014 while the real-time PM₁₀ levels were recorded at an average of 0.063 and 0.102 respectively. Figure 7-2 shows one of the screen shots from the Monitor Serial Output.

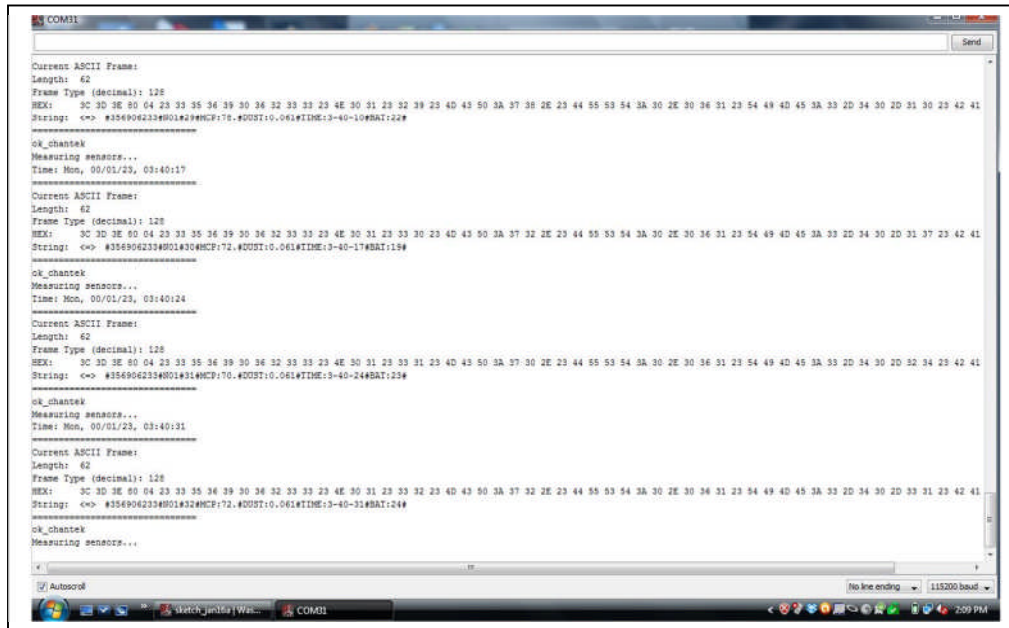


Figure 7-2 A Screenshot of Baseline Environmental Quality Data on a Monitor Serial Output

On 16th February 2014, the waspmote and weather station were successfully installed on site (Case Study C) (see Figure 7-3). The installation took about 1½ hours. For security reasons, they were installed within the construction site which was well guarded and monitored by construction personnel. The waspmote and weather station were put in place 1.4m above the ground and at a position of 4m from the construction hoarding and approximately 6m from the nearest sensitive receptor. Figure 7-3 shows a photograph of the waspmote together with the weather station that was installed on site.



Figure 7-3 Waspmote Installed on Site

7.3.2. THE EVALUATOR

Usability testing is a process that employs people, as testing participants who are representative of the target audience, to evaluate the degree to which a product meets specific usability criteria (Baxter and Courage, 2005). In this case, this research needed to engage with members of environmental management teams, skilled people from one of the most complex and dynamic industrial sectors.

As discussed in Chapter 3, environmental officers by profession are normally busy people (United Nations Human Settlements Programme (UN-HABITAT), 2008) and are 'mobile' as they always moving within the site or intra-projects (Bowden, 2005). Thus it was difficult for them to commit as a participant of this research throughout the whole process. Furthermore, the reasons discussed earlier in Section 7.3.1, it is difficult for a person to obtain access to any construction projects. As a result, out of four experts (in the user requirement stage), only one expert (EXMAL04) has continued to participate as an evaluator in the usability evaluation stage. Fortunately, EXMAL04 is currently attached to Case Study A and has had experience of working for 5 years in one of the construction projects in Putrajaya, the place where Case Study B is located.

For the rest of the evaluators for the usability testing, four persons participated from each of the case studies to make it thirteen (13) persons in total, with nine (9) persons in Malaysia and four (4) persons in the UK for each usability testing session. The selection

of the evaluator was a made easier as they were nominated by the management of the companies for each case study.

However, it is important to highlight that because of this research was conducted iteratively, the first version of the high-fidelity prototype as discussed in the Chapter 6 has been gradually improved to the second version until it become the third version. Basically the areas of improvement were in terms of graphical user interfaces, rearrangement of webpages additional data entry and features. All of these improvements will be discussed in details in the next following sections.

And due to this iterative approach, this research required two usability sessions for each case study. Thus, to maintain the same thirteen (13) persons for each session was very difficult due to their busy job schedules and commitments. As a result, in the second usability testing sessions, some of them were replaced by other team members from the same organisation. Even though thirteen (13) persons were involved for each session, the fact is that a total of seventeen (17) persons were involved in the prototype evaluation stage for this research.

This number of evaluators has proved, in practice, to be an acceptable number of evaluators for usability testing. Based on previous work by Nielsen and Molich (1990a), three to five evaluators are deemed to be sufficient to detect the majority of usability problems. This fact, however, is currently being debated as Faulkner (2003) demonstrates that 5 users' actions may reveal only 55% of the usability problems; below the 80% accuracy rate required for finding usability problems. Faulkner (2003) adds that is advisable to run the maximum number of evaluators that schedules, budgets, and availability allow, but that a minimum of 10 users would achieve the 80% accuracy rate. Therefore, by taking into consideration the availability of the environmental management team members, geographical boundaries, time and budget constraints, this research is comfortable with the number of evaluators as shown in Table 7-3.

Table 7-3 Participants in the User Requirement Studies and Prototype Evaluation

Id.	User Requirements Study	Usability Testing		
		Prototype Version 1	Prototype Version 2	Prototype Version 3
Environmental Experts				
EXMAL01	X			
EXMAL02	X			
EXMAL03	X			
EXMAL04	X	X		X
Environmental Management Team - Malaysia				
USERMAL01		X		
USERMAL02		X		
USERMAL03		X		X
USERMAL04		X		X
USERMAL05		X		
USERMAL06		X		X
USERMAL07		X		X
USERMAL08		X		
USERMAL09				X
USERMAL10				X
USERMAL11				X
USERMAL12				X
Environmental Management Team - UK				
USERUK01			X	X

Id.	User Requirements Study	Usability Testing		
		Prototype Version 1	Prototype Version 2	Prototype Version 3
USERUK02			X	X
USERUK03			X	X
USERUK04			X	X

7.3.3. DEMONSTRATION AND EVALUATION

Usability testing is a common tool used to evaluate the usability of a mobile application within the development process. According to Kallio and Kaikkonen (2005), usability tests are usually conducted using a think aloud protocol that is based on Ericsson and Simon's work (1980). Many researchers like Benbunan-Fich and Benbunan (2007), Kjeldskov et al. (2005) and Kallio and Kaikkonen (2005) themselves have adopted the same approach for their usability testing of a mobile application. In their research, users were given tasks and encouraged to think aloud while trying to accomplish the tasks. This gave them the information that they needed to know on how a user interface matches the natural human way of thinking and acting, and highlights the features and processes that need to be improved.

For this research, the selected environmental managers and officers in Malaysia and the United Kingdom acted as the evaluators and had the opportunity to test the functions of the ENSOCS web by using smartphones. Prior to this, the evaluators were asked to fill in a questionnaire about their details and their current practices in environmental surveillance and monitoring. The respondents were then required to evaluate the ENSOCS web and highlight the usability problems which they found during the process. In order to perform this evaluation, the respondents were asked to perform pre-defined tasks and encouraged to think aloud while trying to accomplish the tasks in front of the researcher at the actual construction sites. The list of tasks was as follows:

- **Task 1** Pretend that you are new to environmental inspection on a construction site, and not very familiar with best practice in sedimentation control. Find out the best practice for sedimentation control and the important areas to emphasise during a site inspection particularly on sedimentation control. Please write down the first three sentences under the heading of “Check”.
- **Task 2** You would like to carry out an environmental inspection on the selected construction site for the first time, and are wondering what surrounding environmental sensitive receptors there are and the potential source of pollution from the activities on site. Find and write down a list of environmental sensitive receptors which are associated with the said construction site.
- **Task 3** Pretend you are now attending an environmental meeting at the site office, and you are required to update your management on the status of the environmental checking and corrective action. Retrieve all the relevant previous inspection reports and obtain real-time environmental monitoring data. Please write down the date, reference number and the subject of the latest inspection report. Next, write down the frame number and MCP value for the real-time environmental monitoring data.
- **Task 4** At the construction site, you have spotted that oil containers are placed on the bare ground and oil spill has been spotted on the ground. Take a photo of this non-compliance using your smartphone. Then by browsing the ENSOCS web through your smartphone, prepare the report by inserting this finding into the Web, provide other relevant information to support this finding, and submit and review the report.
- **Task 5** Email the report as in Task 4 to the relevant authorised person.
- **Task 6** Update the report as in Task 4 by uploading and attaching the photograph to the report.

In this evaluation session, video and audio recording of the session was carried out. The video, however, only captured the hand of the evaluator holding the smartphone while performing the task given. In addition, the time taken to accomplish the tasks using the prototype was recorded and then compared with that of traditional methods or paper forms. The participants were then interviewed (which always involved a discussion) and were asked to complete questionnaires that probed their subjective views on the usability of the prototype. Even though the number of usability problems discovered by

the usability test was considered to be relatively low, valuable feedback for the improvement of the prototype application was provided.

Each evaluation session took almost two hours to be completed. This included the presentation, demonstration, walk around the construction sites, evaluation and interviewing. This has proved, in practice, to be almost the maximum acceptable time that a subject is willing to participate in a session (Ghaoui, 2006; Gucciardi, Cameron et al. 2007).

7.3.3.1. FIRST DEMONSTRATION AND EVALUATION RESULTS – MALAYSIA CASE STUDIES

The demonstration and evaluation with the environmental management teams within the two Malaysian case studies revealed a number of problems with the prototype system. The details are given in Table 7-4.

Table 7-4 Problems with the Prototype Application brought out in the First Demonstration and Evaluation

Nos.	Page/Function/File	Problems
1.	Overall Webpage layout	<ul style="list-style-type: none"> • Some of the web pages were not responsive enough to work on the mobile web. The evaluators had to zoom in/out to enlarge the font and form. • Some evaluators were not comfortable with the layouts that have texture within it as it was sometimes disturbing.
2.	Tasks <ul style="list-style-type: none"> • Taking a photograph 	<ul style="list-style-type: none"> • The application comes with a cluttered screen due to too much information being on display on one screen. Having a button within a web form to activate the smartphone's camera to take a photograph was not a good idea as the

Nos.	Page/Function/File	Problems
	<ul style="list-style-type: none"> <li>• Email <li>• Inspection Checklist 	<p>evaluators seemed to confuse this with the button to submit the form.</p> <ul style="list-style-type: none"> <li>• Any non-compliance should be issued out to dedicated personnel. Thus, the user should have an option to select the recipient of the report. <li>• The inspection report was directly emailed to the administrator once it completed and uploaded to the database. The evaluator might have second thoughts before sending it out or there was the possibility of sending an email incorrectly (by mistake). <li>• The inspection checklist in the opinion of evaluators was incomplete due to missing a form to state the corrective actions that needed to be taken.
3.	<p>Best Practices</p> <ul style="list-style-type: none"> <li>• Font Size <li>• Sentences 	<ul style="list-style-type: none"> <li>• Some of pages were not responsive enough to adjust the layout and font to the mobile device context. <li>• Too long sentences to describe the best environmental practices being on display on one small screen. <li>• The evaluators suggested that is useful to have environmental bad practices as well.

Nos.	Page/Function/File	Problems
4.	Maps <ul style="list-style-type: none"> • Environmental Sensitive Receptors 	<ul style="list-style-type: none"> • The icon on the map page is not suitable as it took more space within a small screen. • It was not necessary to display on the map the surrounding area within 3km of the project site.
5.	Events <ul style="list-style-type: none"> • Previous inspection reports 	<ul style="list-style-type: none"> • No information about the status of any non-compliance, whether it was still active or had been closed (rectified).
6.	Size of the Screen	<ul style="list-style-type: none"> • Some of the evaluators were not comfortable with the screen size of the iphone 3/4 and kept on comparing it with the bigger screen size of their Samsung S4.
7.	Response Speed	<ul style="list-style-type: none"> • Uploading a photograph together with the inspection report to the database always took a long period and sometimes was unaccomplished due to the size of the data and poor 3G network connection.
8.	Terminology/Function Headings	<ul style="list-style-type: none"> • Some evaluators did not understand the terms used or failed to relate to the function headings within the anticipated tasks. For example, some of the evaluators were not able to figure out that the previous inspection reports were under the function “Events”.
9.	Receive and respond	<ul style="list-style-type: none"> • Preparation of surveillance report is not the end of the environmental

Nos.	Page/Function/File	Problems
		management process. As in Plan-Do-Check-Act concept, it is good to have an additional function that would help the users to conduct Corrective Action and prepare the report corresponds to the issued surveillance report.

7.3.3.2. FIRST IMPROVEMENT FOR PROTOTYPE APPLICATION

Before proceeding with the demonstration and evaluation with the environmental management team in Case Study 3 in the UK, the prototype underwent a major revamp in an effort to address the issues listed in Table 7-4. Basically, the overall layout was overhauled and the contents were revised with some omissions and additions made to the old version of the prototype. As a result, an altered prototype was produced with a new layout, a rearrangement of functions and pages, renamed functions, etc. Table 7-5 presents the detailed improvements that were made to the old version of the prototype.

Table 7-5 First Improvements on the ENSOCS Prototype

Nos.	Page/Function/File	Changelogs
1.	Overall Webpage layout	<ul style="list-style-type: none"> • A full revamp was made on the layout and the CSS now integrates together with the Fluid Grid Layout to create a more responsive web. • The ‘main colour’ of the layout was kept plain.
2.	Tasks <ul style="list-style-type: none"> • Taking a photograph • Email 	<ul style="list-style-type: none"> • A separate page to take or upload the photographs was provided. • The users were given an option to select the recipient of the report.

Nos.	Page/Function/File	Changelogs
	<ul style="list-style-type: none"> • Inspection Checklist 	<ul style="list-style-type: none"> • A new page to show the security question before sending an email is provided. • The form to state the corrective actions that need to be taken was provided in the checklist.
3.	<p>Best Practices</p> <ul style="list-style-type: none"> • Font Size • Sentences 	<ul style="list-style-type: none"> • Fluid Grid Layout managed to address this issue as it was able to adjust the layout and font to the mobile device context. • The sentences have been shortened and brief information has been provided. • Environmental bad practices can be accessed in the photograph gallery.
4.	<p>Maps</p> <ul style="list-style-type: none"> • Environmental Sensitive Receptors 	<ul style="list-style-type: none"> • The icon on the map page was removed. • The map of the surrounding area (within 3km from the project site) was replaced with a pre-identified environmental sensitive receptors' map.
5.	<p>Events</p> <ul style="list-style-type: none"> • Previous inspection reports 	<ul style="list-style-type: none"> • The status of non-compliance - whether it is still active or has been closed (rectified) - was made available in the latest version. • The Function of Event has been

Nos.	Page/Function/File	Changelogs
		renamed to Historical Data.
6.	Size of the Screen	<ul style="list-style-type: none"> Fluid Grid Layout managed to address this issue as it was able to adjust the layout and font to the mobile device context and enhance the visibility of the web.
7.	Response Speed	<ul style="list-style-type: none"> The inspection checklist was divided into two parts. The first part is for users to enter the observation details and submit the report, while part two is for the user to take or upload a photograph(s). Thus, the size of the web pages and data became smaller and, hence, improved the speed.
8.	Terminology/Functions Heading	<ul style="list-style-type: none"> A rearrangement was made to the pages and some of the functions were renamed and added in.
9.	Receive and respond	<ul style="list-style-type: none"> Additional functionalities were added so that the users are able to conduct Corrective Action and prepare the report corresponds to the issued surveillance report.

7.3.3.3. SECOND DEMONSTRATION AND EVALUATION RESULTS – UNITED KINGDOM CASE STUDY

The second demonstration and evaluation session was carried out with the environmental management team in Case Study 3 in the UK. It was carried out after the prototype had been revisited and revised based on the feedback from the evaluators during the first demonstration and evaluation session in Case Studies 1 and 2. Most importantly, it should be emphasised that it was the first time that the environmental management team in Case Study 3 had been exposed to the prototype. However, despite it being their first experience of handling the prototype, all of the participants seemed to be satisfied with the prototype. Of course, there were still a few usability problems but the number of the usability problems was reduced to only three issues during this demonstration and evaluation session. The details are as given in Table 7-6.

Table 7-6 Problems with the Prototype Application in the Second Demonstration and Evaluation

Nos.	Issues	Descriptions
1.	Maps <ul style="list-style-type: none"> • Environmental Sensitive Receptors 	<ul style="list-style-type: none"> • One evaluator found it difficult to find the Environmental Sensitive Receptors (ESRs) as she did not expect that the ESRs would come under the function of Map.
2.	Response Speed	<ul style="list-style-type: none"> • Even though a separate page had been provided the problem of uploading the photograph still occurred occasionally due to poor 3G network connection.
3.	Information about the prototype's features and services	<ul style="list-style-type: none"> • The evaluator should be informed of how many services are available and what they are used for.

7.3.3.4. SECOND IMPROVEMENT OF THE PROTOTYPE APPLICATION

The results from the demonstration and evaluation session with the environmental management team in Case Study 3 demonstrated that there were issues pertaining to the suitability of the features under certain functions, the uploading waiting time and the information about the prototype's features and services. As the feedback was less than that received in the first demonstration and evaluation, the prototype was again refined for the second time; this time only a few amendments were necessary. Table 7-7 presents the details on the second improvement of the prototype application.

Table 7-7 Second Improvement on ENSOCS Prototype

Nos.	Issues	Descriptions
1.	Maps <ul style="list-style-type: none"> • Environmental Sensitive Receptors 	<ul style="list-style-type: none"> • Environmental Sensitive Receptors (ESRs) were moved out from the function of Map and were made available on a dedicated page. However, a link to the map was provided and the map shows where the ESRs have been upgraded with tagging in place.
2.	Response Speed	<ul style="list-style-type: none"> • An amendment has been made to part two of the inspection checklist whereby some of the forms were moved into part one. This was to reduce the size of part two.
3.	Information about the prototype's features and services	<ul style="list-style-type: none"> • Brief descriptions of the prototype's features and services available were given in the presentation prior to the next demonstration and evaluation.

7.3.3.5. THIRD DEMONSTRATION AND EVALUATION RESULTS – UNITED KINGDOM CASE STUDY

Upon completion of the second refinement, a final demonstration and evaluation session was carried out with the environmental management team in Case Study 3. This was to demonstrate to the evaluators that all the feedback had been considered and further refinement had been undertaken accordingly. It was also to show the latest version of the prototype to the evaluators and to evaluate it simultaneously.

Overall, the evaluators were satisfied and even praised the latest prototype and stated that it was now easier to use. However, the only remaining problem is still with regard to the network connection. It is well recognised that uploading a photograph via the mobile web is not the easiest practice but from this research's point of view, it is important to add it in as the photograph is part of supporting evidence for any non-compliance report. Therefore, the immediate solution to this problem is by giving an option to the users to update the report by uploading the photograph when a strong 3G network signal or WiFi is available.

7.3.3.6. FOURTH DEMONSTRATION AND EVALUATION RESULTS – MALAYSIA CASE STUDIES

At this stage, the prototype had undergone two refinements based on the feedback gathered during the first and second demonstration and evaluation sessions in both Malaysia and the UK. During this final demonstration and evaluation session, four evaluators in the first session were replaced with four new evaluators with three new evaluators coming from Case Study 1 and one new evaluator coming from Case Study 2. Thus, these four evaluators had the opportunity to explore the latest version of the prototype without any prior exposure to any demonstration and evaluation session.

With regards to the usability problems, the similar problem as had occurred in the Case Study 3 happened once again. Even though a separate page had been provided, the problem of uploading the photograph still occurred occasionally due to poor 3G network connection. For the same reason, one evaluator encountered a problem where the button to submit the inspection report did not appear and the page had to refresh.

Overall, positive feedback was given and the concept was well accepted by the evaluators, including the new evaluators. From the research point of view, the feedback from the new evaluators were very important as there was no bias in their views since they came from a totally new set of users of the prototype.

Additionally, as a reaction to the problem of 3G network connection, some of evaluators suggested that the research should look into developing the mobile app so that it could work offline and then to only send the report once the internet connection is available.

7.4. REFINED PROTOTYPE SYSTEM

Based on the comments and suggestions obtained in the usability testing, the researcher has revised the prototype while maintaining the design objectives. Basically, the prototype application has been redesigned and refined in terms of the graphical user interface, additional data-entry for the inspection checklist and rearrangement of the pages. Due to these changes, the conceptual model has been revisited and amended accordingly. The following section will present and discuss the latest version of the prototype (version 3.0); the same version which was demonstrated and evaluated in the final demonstration in Malaysia and the UK. It is important to recap that, for this latest prototype version, no usability issues were found during the final demonstration and evaluation in both Malaysia and UK except for the loading of the prototype's webpage and the long photograph uploading time which was due to weak 3G network connection.

7.4.1. THE REVISED CONCEPTUAL MODEL

Figure 7-4 shows the revised conceptual model for the prototype. The user in the outer box of the diagram remains the most important component in the system. The numbered boxes (from 1 to 11) are the functions of the system (e.g. Login to ENSOCS) while the boxes with numbers from D1 to D19 are the items included in the class diagram (e.g. D1 – Contact Detail).

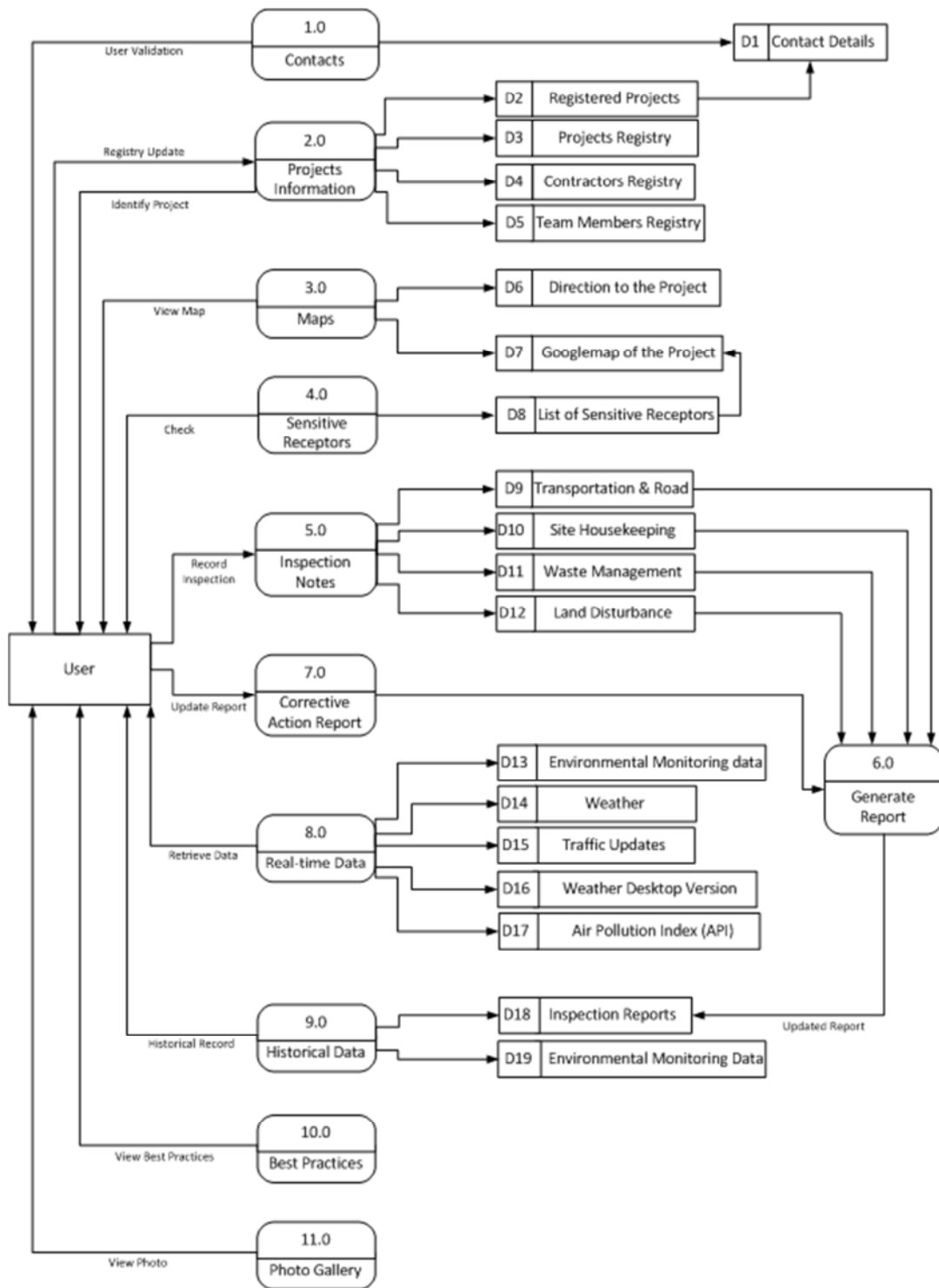


Figure 7-4 The Revised Conceptual Model of the ENSOCS Application

As can be seen in Figure 7-4, the functions of the system (represented by the numbered boxes from 1 to 11) have been increased from eight (8) to eleven (11). This is due to the additional functions of Corrective Action Report (Box No.7.0) and Photo Gallery (Box

No.11.0) whilst Box 4.0 (Sensitive Receptors) represents the upgraded class diagram which now has become one of the main functions. It is also important to highlight that a few functions have been renamed to take note of the feedback of the evaluators. The functions that were renamed are shown in Table 7-8.

Table 7-8 Renaming of the Functions

Nos.	Prototype Version 1		Prototype Version 3	
	Function No.	Old Name	Function No.	New Name
1	4.0	Tasks	5.0	Inspection Notes
2	5.0	Live Boards	8.0	Real-time Data
3	6.0	Events	9.0	Historical Data

7.4.2. GRAPHICAL USER INTERFACE

The researcher admits that the user interface of the old version was not responsive enough to adapt layout and content for the viewing of contexts across a spectrum of digital devices. Furthermore, the intention to display a lot of information within a limited screen made the text and icons become small in size.

However, developing a responsive web so that the sites adapt to fit a variety of different resolutions and screen specifications effectively has been proven to be time-consuming because it requires hand-coded media queries and complex mathematical calculations (West, 2012). Fortunately, Adobe Dreamweaver CS6 has a Fluid Grid Layout feature that makes designing for multiple screens much easier (West, 2012). Thus, the latest version of prototype has been enhanced by using the Fluid Grid Layout together with the existing Cascading Style Sheets (CSS) and programming languages. It received good feedback from the evaluators during the final demonstration and evaluation session. Therefore, it managed to solve the above mentioned problems.

First and foremost, the icons on the main menu were replaced by graphical panels. Similar to the icons, they link to the main features of the prototype but with more visibility. Figure 7-5 presents the refined main menu of the prototype.

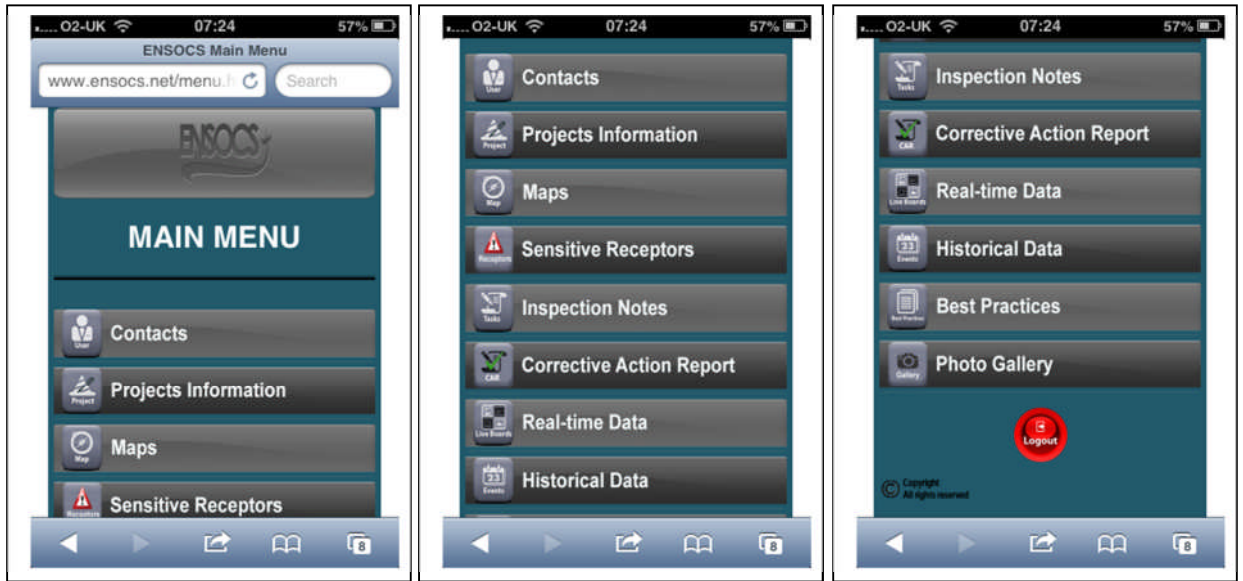


Figure 7-5 Main Menu of the ENSOCS Prototype (Version 3)

Next changes have been made on the text and sentences. To provide information on environmental best practices, a brief explanation on each key issue is provided in the latest version. The users then have an option to read these details by clicking on the link. By using the Fluid Grid Layout, the size of text and the position of the icons and the graphical panels are automatically adjusted depending on the type of browsers used. Figure 7-6 shows a sample of the print screen of the webpage for environmental best practices.

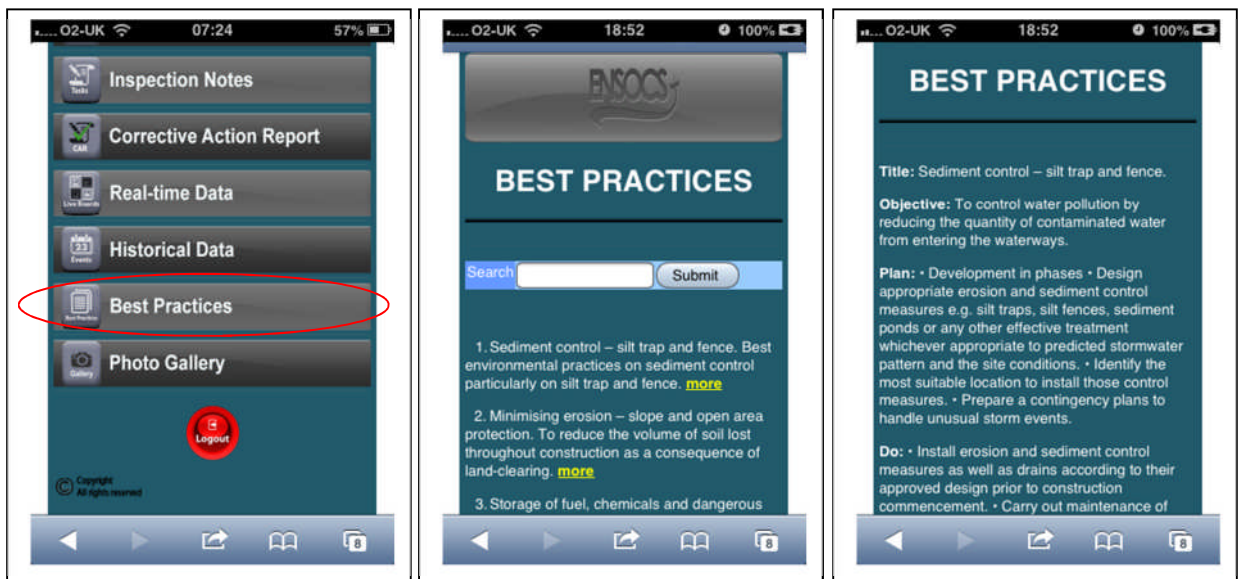


Figure 7-6 The Print Screen of the Webpage for the Environmental Best Practices

7.4.3. ADDITIONAL DATA-ENTRY FOR THE INSPECTION CHECKLIST

During the first session of the demonstration and evaluation in Malaysia, the evaluators gave feedback specifically on the inspection checklist. They requested that the prototype should allow the environmental management team to put the required corrective action to be taken in any issued-out report. As a result, changes were made to the checklist. The overall layout still remained the same; however, there is now an additional data entry form for the required corrective action. The relevant part of the refined checklist is shown in Figure 7-7.

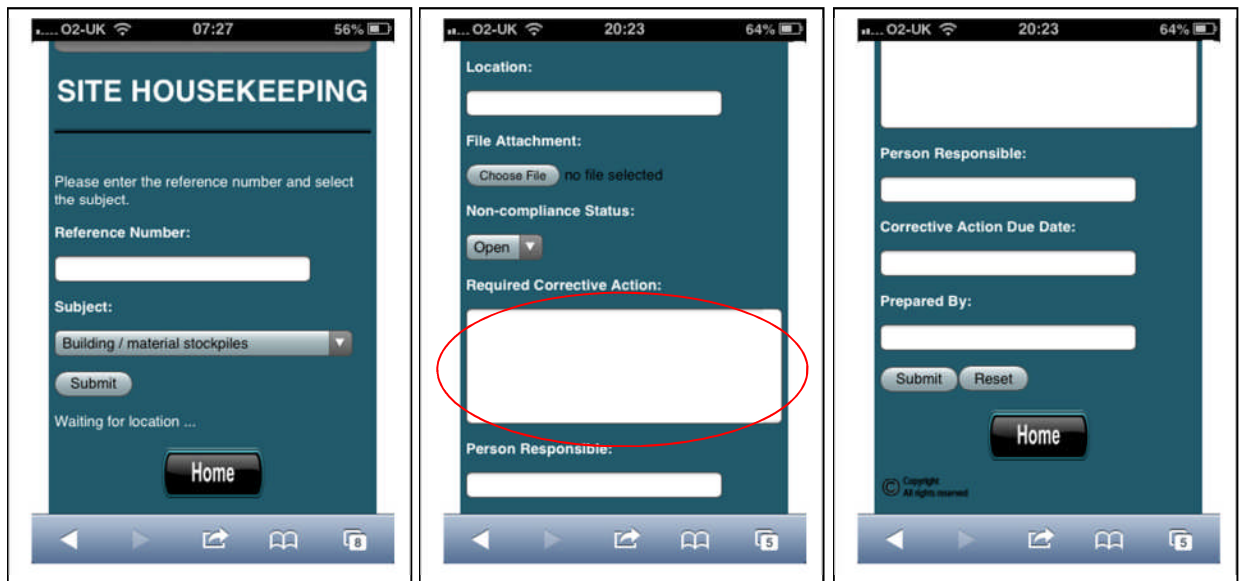


Figure 7-7 Part of the Refined Inspection Checklist Showing Entry Form for Required Corrective Action

Additionally, the evaluators raised concern about the possibility of sending an email incorrectly (by mistake). In the old version, the report would automatically be sent out to the appropriate person but now there will be an additional page to confirm the action and the recipient's email address. Thus, once the inspection checklist has been filled up, the users will review the report and undertake the amendments, if any. When they have confirmed the report only then can they send the report through an email. Next, they will have to select the recipient's email address and click a confirmation to send.

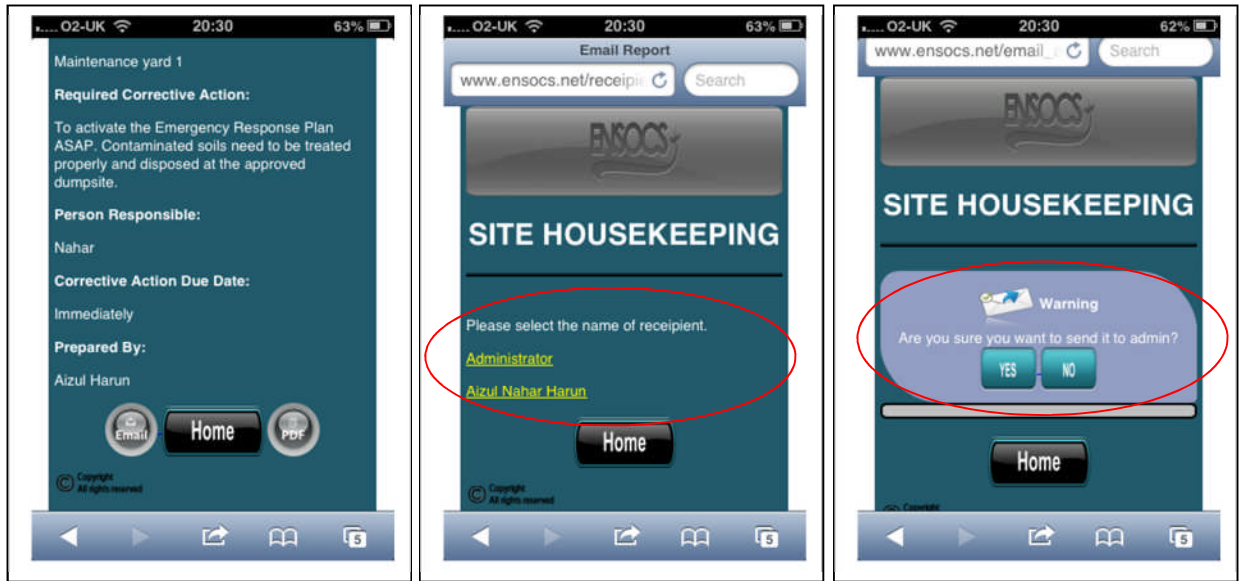


Figure 7-8 Sending a Report via Email

7.4.4. REARRANGEMENT OF PAGES

Rearrangement of the prototype's web pages has also been undertaken. Previously, the information about the environmental sensitive receptors was part of the map's function. But, since the evaluators seemed to find it difficult to find the information about the environmental sensitive receptors, dedicated web pages to show the information on the environmental sensitive receptors were provided in the latest prototype version. The type of information given and the way to display information have also been revisited and improved. The display on the map of the surrounding area within 3km of the project site was omitted and replaced with a list of pre-identified environmental sensitive receptors with an option to show them on map with tagging. The users then may click on the tagging in order to get more detailed information.

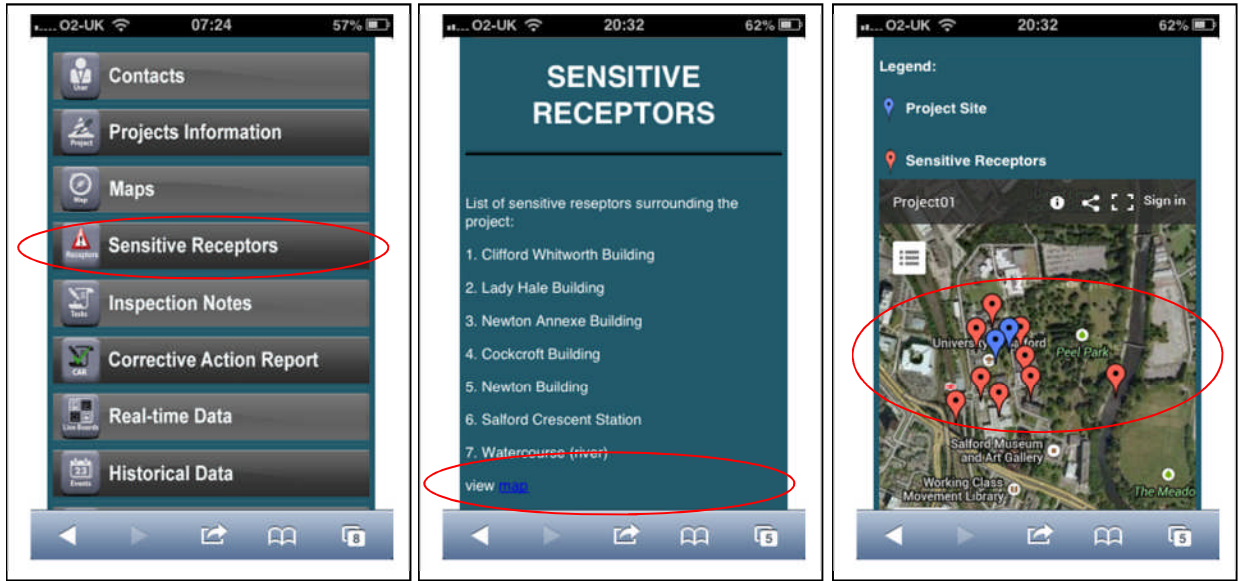


Figure 7-9 Print Screens Showing Information on the Environmentally Sensitive Receptors

In addition to the above, the features to assist in taking the photograph have now been separated from the checklist form. This was to address the feedback from the evaluators that the original icon (button) to activate the camera function was not suitable where it was. Furthermore, by undertaking that separation, it reduces the size of the submitted data hence improving the delivery of the data to the database.

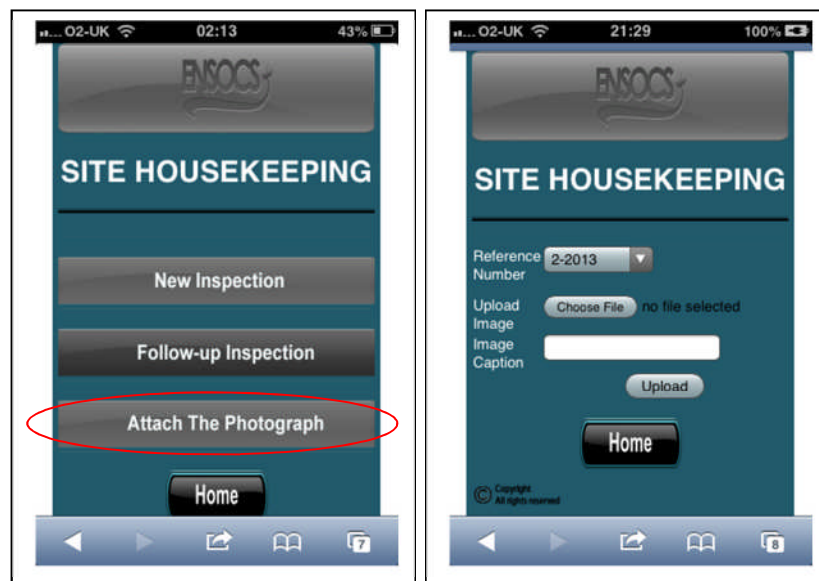


Figure 7-10 Uploading the Photograph

7.4.5. ADDITIONAL FEATURES

Additional features have also been added into the latest version of the prototype. The evaluators suggested that the system must enable users to receive and respond to any non-compliance report (NCR). Therefore, in the latest prototype version, the responsible person who received the NCR may use the function of “Corrective Action Report” as response to the issued NCR. By referring to the reference number, they would now be able to prepare and submit a report on the rectification works that have been undertaken on site. As a follow up, the NCR issuer may use the function of “Follow-up Inspection” under the main menu of “Inspection Notes” to verify the rectification works.



Figure 7-11 Features of the Correction Action Report

Additionally, the evaluators suggested that it would be better to have available the features of environmental best and bad practices rather than showing only good practices. Thus to address this issue, the photographs' galleries will show photographs of both good and bad environmental practices so that users can see them and learn from them.

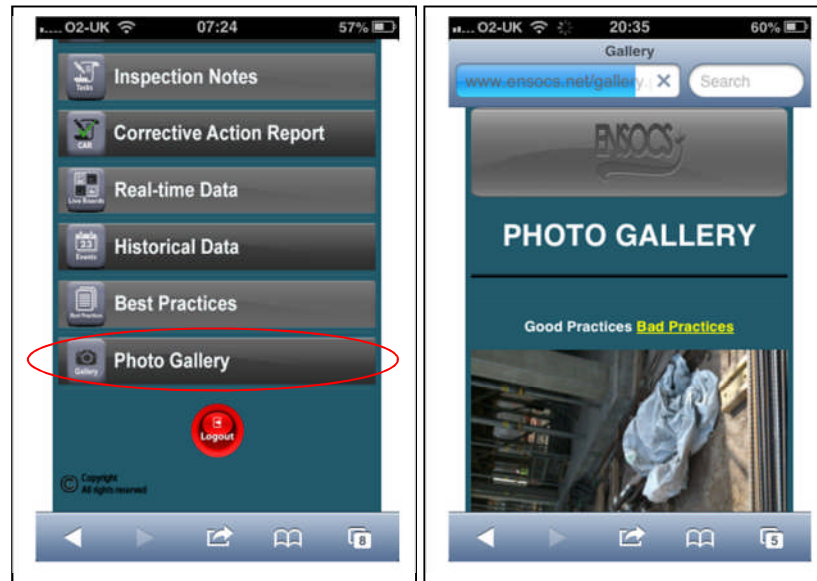


Figure 7-12 Function of the Photo Gallery

7.5. EASE OF USE OF THE ENSOCS PROTOTYPE

During the evaluation questions were also asked about the prototype's ease of use after it had gone through two refinements. As shown in Table 7-9, the overall feedback was positive as none of the evaluators disagreed with, or were dissatisfied with, the prototypes and, in fact, all of them whether in Malaysia or in the UK were agreed 100% that the information in the prototype was generally what they expected to find and it was clear on the system where they could find the information about the guidelines.

It was also observed that, during the demonstration and evaluation sessions, the evaluators in Case Study 2 (Malaysia) and Case Study 3 (United Kingdom) were more favourable towards the prototype. It can be seen in Table 7-9, only one evaluator from each case study stated that they neither agreed nor disagreed with the statement that "I always know where I am on the site". Other than that, most of evaluators in Case Study 2 (Malaysia) and Case Study 3 (United Kingdom) agreed or strongly agreed with the other five statements.

Unlike Case Study 2 (Malaysia) and Case Study 3 (United Kingdom), even though there was no negative feedback on the prototype from the participants in Case Study 1 (Malaysia) but their response was mixed. However, it is important to note that three out of the five evaluators in Case Study 1 during the second demonstration and evaluation

were different people to those who had taken part in the first demonstration/evaluation because of the unavailability of the previous evaluators. UserMAL11 (a new evaluator) was one of evaluators that contributed to the “neither agreed nor disagreed” feedback for the statements of “I always know where I am on the site”, “I was confident that I would be able to find the information needed to complete the task” and “It was easy to learn how to perform new tasks on the site”, respectively. In addition, it seems that ExMAL04 and UserMAL07 had not really fully taken on board the two improvements that had been made to the prototype. ExMAL04 indicated neutral against the statement of “It was easy to learn how to perform new tasks on the site” whereas UserMAL07 stated that she neither agreed nor disagreed with the statements of “This site is easy to navigate”, “I was confident that I would be able to find the information needed to complete the task” and “It was easy to learn how to perform new tasks on the site”, respectively.

Overall, all the environmental management teams found that the prototype was: easy to navigate (92%); contained the information where they expected to find it (100%), and clearly indicated where they could find information about the guidelines (100%). Some of them might have taken some time to adapt to the new layout and features of the prototype as just 77% of the evaluators always knew where they were on the site and agreed that it was easy to learn how to perform new tasks on the site. But most importantly, the majority of them (85%) were confident that they would be able to find the information needed to complete the task. This shows that the prototype was not just designed to be user-friendly but also that it was based on the widely-used industry standards for mobile applications.

Table 7-9 Ease of Use of the ENSOCS Prototype

Ease of Use of the ENSOCS Prototype	Case Study 1 (Malaysia)			Case Study 2 (Malaysia)			Case Study 3 (UK)		
	Rating/Number of Evaluators			Rating/Number of Evaluators			Rating/Number of Evaluators		
	Rating 5	Rating 4	Rating 3	Rating 5	Rating 4	Rating 3	Rating 5	Rating 4	Rating 3
This site is easy to navigate	1	3	1	0	4	0	2	2	0
The information was generally where I expected to find it	1	4	0	1	3	0	3	1	0
It is clear which pages have the information I need about the guidelines	1	4	0	1	3	0	3	1	0
I always know where I am on the site	0	4	1	0	3	1	1	2	1
I was confident that I would be able to find the information needed to complete the task	0	3	2	1	3	0	1	3	0
It was easy to learn how to perform new tasks on the site	1	1	3	1	3	0	1	3	0

Legend:

Rating 5 – Strongly Agree

Rating 4 – Agree

Rating 3 – Neither Agree or Disagree

7.6. BENEFITS OF THE PROTOTYPE APPLICATION

Through the interviews with the evaluators after the demonstration and evaluation session, several benefits arising from the prototype’s application were identified. The findings give an indication of the practicality and the perceived usefulness of the prototype and provide useful feedback for any future implementation. The evaluators gave very positive feedback and a brief overview of the qualitative feedback generated during the interviews is summarised in Table 7-10.

Table 7-10 Benefits of the Prototype Application

Issues	User feedback
Identified Benefits (Communication)	<ul style="list-style-type: none"> • “Definitely, the system has improved communication as it would cut the time short by one click to distribute the information to others.” • “Yes, definitely because we do not have to be physically there (to perform grab sampling).” • It is good for new staff to get information via the map. • “This web also makes it easy to make contact with our peers.” • It is easy to report the findings and enable fast action to be taken by the respective parties. • “The ENSOCS web would cut the time short but rectification works on the ground will still depend on user reaction. It will be status-quo if they do not read the email.” • “Any non-compliance issue like a spill incident on site, I could send it directly straight over to the environmental manager without needing to come back to the office to pick up the phone. I could just send it straight away and so yes it is definitely a way forward. This might be something that we need to have on mobile devices and take out on site with me.” • “I think it will improve knowledge. It has the receptor there

Issues	User feedback
	<p>(information on the sensitive), and then I need to go where that is (priority/targeted area). I think the receptor might be useful.”</p>
<p>Identified Benefit (Task performing and reporting)</p>	<ul style="list-style-type: none"> • “The system is stand-alone. We do not have to be physically there to carry out the works and key-in the data.” • “Yes, definitely (would benefit environmental surveillance on construction sites) because sometimes an incident might happen when we are not there (at the project site) or late at night but the system would be able to alert the user in any case of non-compliance.” • It would avoid the cases where photos are missing, forgotten, etc. • Real-time data would keep the contractor informed about the problem and what needs to be done (strategize). • “It is good for check and balance because we cannot trust 100% the monitoring results from the laboratories.” • It is easy to produce a report and see “best practices” to refer to by one click. • The results of the environmental quality monitoring can be accessed instantly, so that respective parties can be notified accordingly. • “Definitely (would benefit environmental surveillance on construction sites). Basically, if say something (happens on site), you’ve got that straight away and can take a photo of it. Rather than just walking around in general on the site inspection when you don’t have a camera with you. So if I’ve got that with me, a snap shot of any evidence can be done straight away. You can report it straight away and I do think it’s a good tool to have.” • “The real time monitoring would help. Certainly the alerts when you near a threshold - that is a really good system.

Issues	User feedback
	<p>Certainly in the area where you've got residents, there's potential for nuisances. You don't need complaints because the evidence (shows the threshold) still below the threshold. So I think those (features) are very useful.”</p> <ul style="list-style-type: none"> • “It is a good central location to capture many different things in one place. Its easily retrieved (data) for learning and for monitoring. So we can use it (online best management practices) to show bad and good for sharing (of knowledge) so that everybody can improve.”

As shown in Table 7-10, it was found that the prototype would be able to improve the efficiency, effectiveness and performance of the environmental team members in their daily activities. Thanks to the real-time environmental quality monitoring features, the mobility of the devices, the inspection data collection features, the information and services provided by the prototype itself, it can improve their communication, enable environmental team members to accomplish their task more quickly and promotes knowledge sharing among them. For instance, when compared to the current traditional methods for the preparation and submission of a surveillance report, the time frames have been shortened from at least a minimum of 11 hours (excluding the provision of approximately 1 hour for opening and closing conference of each inspection) to less than 20 minutes for the same purpose (Table 7-11). Similar effects have been shown for obtaining environmental quality data where the time taken was reduced from at least a minimum of 12 hours to less than 10 minutes. It shows that the prototype can significantly help environmental team members accomplish their tasks more quickly and, indirectly, it would enable fast rectification works to be undertaken by the respective parties.

Table 7-11 Time Taken by the Evaluators to accomplish the Predefined Tasks

Task Nos.	Descriptions	Case Study 1 (Minutes)	Case Study 2 (Minutes)	Case Study 3 (Minutes)
Task 1	Max	7.00	5.00	4.00
	Min	2.00	2.00	2.00
	Ave	3.00	4.00	3.00
Task 2	Max	4.00	5.00	3.00
	Min	2.00	1.00	1.00
	Ave	2.40	3.50	2.00
Task 3	Max	7.00	4.00	4.00
	Min	2.00	2.00	1.00
	Ave	3.00	2.50	2.50
Task 4	Max	9.00	8.00	4.00
	Min	3.00	4.00	3.00
	Ave	6.20	5.25	3.50
Task 5	Max	1.00	5.00	2.00
	Min	1.00	2.00	1.00
	Ave	1.00	3.00	1.25
Task 6	Max	3.00	7.00	3.00
	Min	2.00	5.00	3.00
	Ave	2.67	4.50	3.00

In addition, the benefits of the application can be seen in terms of capitalising the “smart objects” under the concept of the “Internet of Things”. The interactions of these smart objects have enhanced communication and enriched the information given to the user.

Chaouchi (2013) states that the interactions of smart objects in the Internet of Things exist in the form of Human-to-Human communication, Human-to-Object communication and Object-to-Object Communication. In this research, similar interactions can be found as follows:

a. Human-to-Human Communication

Human-to-Human communication for ENSOCS was demonstrated by the numbers of emails containing the inspection reports which were sent out by the users to the respective recipients. A total of twenty six (26) emails were sent out by the users during the prototype's demonstration and evaluation sessions.



Figure 7-13 The Print Screen showing Some of the Emails Sent Out

In addition, even though there were no telephone calls made using the smartphone during the prototype's demonstration and evaluation sessions, the prototype also has a capability to invoke a phone call by clicking a link within the phonebook of ENSOCS. This feature would enable the user to communicate with other people by easily making a phone call.

b. Human-to-Object Communication

The users used the prototype as an inspection tool during the prototype's demonstration and evaluation Sessions. The ENSOCS enabled the users to carry out the inspection, prepare and submit the inspection reports to the database and send it out through emails easily. A total of twenty-six (26) reports were produced by the users during the prototype's demonstration and evaluation sessions.

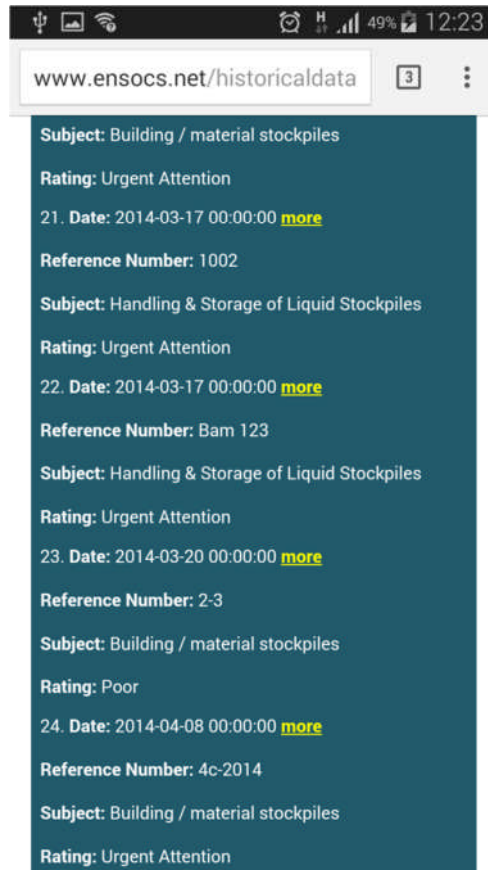


Figure 7-14 The Print Screen Showing the List of Some of the Reports

The ENSOCS prototype also displays the Air Pollution Index (API), real-time Air and Noise monitoring data, and weather and traffic conditions' data. These would provide some indication of the situation surrounding the sites that will help the users to plan their works.

In addition, the capability to send a message using the Short Messaging System (SMS) was demonstrated during the prototype's demonstration and evaluation sessions as well. The threshold of 80dbA for Noise Level and 150g/m³ for PM₁₀ were set so that any reading which exceeded these thresholds would trigger the waspmote to send an SMS to a dedicated telephone number. Even though only one (1) SMS was delivered through-out the sessions due to only one recorded instance of non-compliance, it was still able to demonstrate that the object-to-human communication through SMS existed in this prototype.

c. Object-to-Object Communication

Beside the communication between Human-to-Human and Human-to-Object, the interaction between Object-to-Object could also be seen through the communication between the Noise sensor and the GPRS/GSM module on the waspmote which concluded in the sending out of the message using the SMS. As the noise sensor had recorded a high reading in the sound levels, it triggered the GPRS/GSM module to send one (1) SMS to the dedicated telephone number.

Moreover, as the sensors kept on capturing the readings of the levels of PM₁₀ and sound throughout the prototype's demonstration and evaluation sessions, they also kept on sending the readings to the database. More than 4,500 data were recorded through-out the sessions and these data were made available on ENSOCS for the use of the users.

Finally, the Object-to-Object communication could also be seen in the interaction between the weather rigs and the weather station. In this research, the weather rigs captured the readings of temperature, wind speed and direction and the measurements from the rain gauge. These readings then were sent to the weather station which was synchronized with the Cumulus, a freeware programme for retrieving, storing and displaying data on the web. The significance of these data was that they gave an indication on what is happening on site during the monitoring session. In this case, the high reading of a wind gust on 12th February 2014 alerted the researcher as to the possibility that something might happen to the weather station and that environmental mitigation measures might need to take place (for example, to hoardings which might be affected due to high speed

winds). And, the guess of the researcher proved to be true when the weather station needed attention the next day.

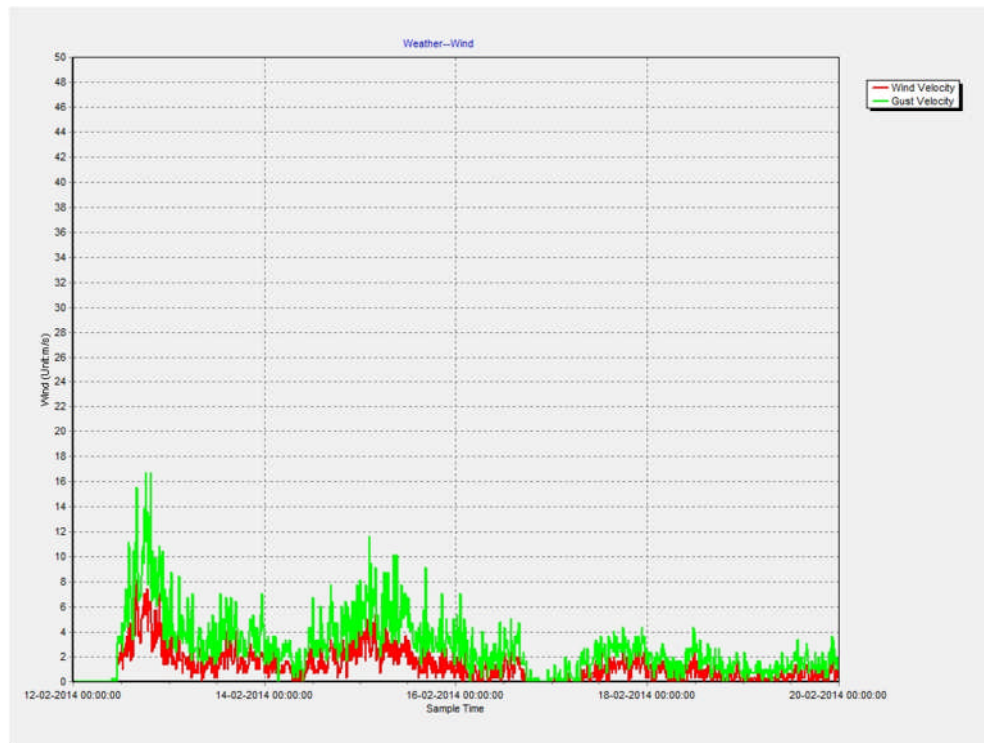


Figure 7-15 The Chart of the Wind and Gust Velocity for the period of 12th – 19th February 2014

7.7. BARRIERS FOR IMPLEMENTATION

Based on the questionnaires and interviews with participants of this research in the UK and Malaysia, several major barriers to the implementation of such a system in environmental surveillance have been identified. These barriers include return on investment, operational cost, legality issues, work procedures issues, technology and technical issues, technology adoption barriers and network infrastructure. Their main concerns are discussed in detail in Table 7-12.

Table 7-12 Barriers for Implementation

No	Evaluators' Feedback	Comments
1.	<p>Return on Investment</p> <p>The decision to adopt this kind of system is subject to the approval of the top management of the company who are always concerned about return on investment. Therefore, it is crucial to identify the 'benefits' it produces as compared to the existing methods in order to justify the acceptance of the system by industry.</p>	<p>Construction companies are profit-oriented companies. Thus, it is important for them to know the return on investment (ROI) so that they can ensure that they will achieve positive outcomes in terms of finances and business operations. However, addressing specific ROI issues is beyond the scope of this research.</p>
2.	<p>Operational Cost</p> <p>Various implementational cost barriers were identified during the evaluation process. Details of these cost barriers are:</p> <ul style="list-style-type: none"> • It requires specialist dedicated and competent resources, i.e. staff with the knowledge to administer and maintain the system. Appointment of new staff would add to company expenditure. • It is anticipated that, in future, the system can only be used by a license holder. There will be a cost in obtaining the license. • A majority of the evaluators would refuse to use their smartphones for their work duties. But for those who would be willing 	<p>This finding shows that cost is an obstacle for the implementation of the prototype. It is good to reveal these issues and this area would provide a basis for future research.</p>

No	Evaluators' Feedback	Comments
	<p>to do so, they would ask the company to bear the cost of the telephone bills. Thus, there is likely to be costs incurred in giving smartphones to staff members and an incurred cost of telephone bills.</p> <ul style="list-style-type: none"> • Proper training is needed for the system to be fully utilised by the targeted user. Cost to provide sufficient training is anticipated. 	
3.	<p>Legal Issues</p> <p>It was pointed out that agreement between the client and the contractors pertaining the usage of the system would be required prior to implementation. It was also pointed out that the photographs attached to the report produced by the prototype might not be valid due to an absence of a date stamp. But this should not be a problem if the prototype is used for internal reporting purposes.</p>	<p>The evaluators of Case Study 3 (UK) had faced a similar problem with their existing system for waste management. Their immediate action was just to stick to a manual camera to capture an image while using the system. However, given that the role of mobile devices in helping to resolve various tasks have now been recognized, of course, they will continually be improved and will be equipped with the latest technologies in the future.</p>
4.	<p>Work Procedures</p> <p>The evaluators highlighted that the implementation of this prototype would affect current working procedures. Therefore, they</p>	<p>Revision to works procedures can be expected as current work procedures</p>

No	Evaluators' Feedback	Comments
	<p>anticipated that some changes to the current working procedures would have to be made if their company pursued adopting the prototype. The following are the details that would affect the work procedures:</p> <ul style="list-style-type: none"> • Some companies will not allow their workers to use a phone at construction sites except for within the designated areas. • The client has to put in the requirement/request in order to instruct and enforce the contractor to use the system. 	<p>are suited to the traditional work methods. However, the evaluators have admitted such a change can be managed as long as there are good tangible benefits on the implementation.</p>
5.	<p>Technology and Technical Issues</p> <p>There was a concern about the technology and the technical issues as follows:</p> <ul style="list-style-type: none"> • Reliability of hardware: This concern was based on experiences of other systems; there were a few occasions where systems were down due to server maintenance, damaged databases and the durability of the mobile devices. • Integration Issues: It would be good to have a prototype that can integrate with the existing company's system. 	<p>These technological and technical issues will be addressed in future research, especially with the emergence of new and more robust technologies (e.g. database replication, cloud web hosting), competent resources and the use of a web hosting provider that is reliable and has a proven track-record.</p>
6.	<p>Technology Adoption Barriers</p> <p>Even though all the evaluators were active smartphone users, it is important to note that not</p>	<p>These findings are expected. A recent study by Global</p>

No	Evaluators' Feedback	Comments
	<p>all construction personnel have a smartphone and are familiar with it. Another important issue, highlighted by the evaluators, was that the older generation might find difficulties in adapting to this kind of system. This is due to several reasons such as age factors, low technical literacy or reluctance to change. Human attitude would also affect technology adoption as a good system might be abandoned due to a lazy user.</p>	<p>Web Index Device has revealed that when it comes to age, the 25-34 years' demographic is the most likely to be connected via smartphone, while those aged between 55 and 64 years are the least likely to own the technology (Mander, 2014). However, in addressing technology adoption barriers especially among the older generation, proper engagement with targeted users through trainings together with improved interfaces and features that suit their needs would address this issue.</p>
7.	<p>Networking Infrastructure</p> <p>Wireless connection reliability and wireless services may not be available in certain areas, especially in the case of rural areas project development.</p>	<p>These networking issues will be addressed in future research, especially with the emergence of new and more robust technologies (e.g. WiMAX, 4G, 5G). Some of the technologies have matured and are now expanding countrywide. The 4G system promises to bring</p>

No	Evaluators' Feedback	Comments
		a communication world with high data rates' transfer, high quality service for multimedia support, seamless connectivity and global roaming across multiple networks (Supa'at et al., 2008).

7.8. DISCUSSION

The demonstration and evaluation sessions have demonstrated that the mobile web should be properly designed to suit the special characteristics of mobile devices. Even though there are few authors, like Mehta (2008), who have simply defined that any website accessed from a mobile device, whether it has been tailored to work on a mobile or not, is a mobile web, the results from this study have shown that a mobile web must be responsive enough to work on mobile devices as otherwise it contributes to many usability issues.

Obviously for this research, the development of the ENSOCS prototype has benefited from the demonstration and evaluation sessions with a group of environmental management teams as evaluators. The session was conducted four times, twice each in Malaysia and the UK. During the sessions, the evaluators have successfully identified the usability issues in the design of the user interface. It is important to note that the concept of iterative development is to successfully improve on, and reduce, the number of vulnerabilities and usability problems each time such a session is held. This can be seen in the current thesis when the nine (9) issues identified during the first session in Malaysia were finally reduced to one problem only during the last session. In fact, that one last problem was not a matter of usability in the user interface design but was more of an implementation hurdle due to a lack of 3G network connection.

Prototype demonstration and evaluation session also enable the evaluators to thoroughly explore the prototype and provide the feedback to ensure sufficient number of, and suitable functions is available on the system. This has resulted that the evaluators were managed to spot the lacking in terms of the system to receive and respond. Hence, the evaluators had proposed an additional function to enable them to conduct the Corrective Action and prepare the report corresponds to the issued surveillance report. This matter has not been discovered during the user requirement studies, thus it deems to be important in enhancing the ability of prototype to support the environmental surveillance.

In addition to that, it is fair to state that the sustainability of a system is more or less depends on the smoothness of the implementation. However, based on the finding in the prototype evaluation for this research, it is worth to acknowledge that even though it is widely accepted that Information and Communication Technology (ICT) contributes positively to the construction industry in terms of supporting tasks, easing communication barriers, speeding up processes and response time and in managing information (Jaafar et al., 2007a, Bowden et al., 2006, Peansupap and Walker, 2005) and increased effectiveness into the process of construction (Ahmad et al., 2010), but still the attributes of the construction players create an obstacle in the implementation. Through the evaluation, it was found that the work procedures and the attitude of the workers towards adoption of the new technologies would not be easily changed in order to facilitate the implementation of the system. Furthermore, as a profit oriented entity, the construction company is very critical about the return of investment and the operational cost. These very important issues were only being discovered through direct engagements with the construction players during the evaluation stage.

In addition, the demonstration and evaluation sessions were useful in highlighting areas of science which can be the subject of future development and whether it is consistent with the views of existing science experts (Anumba and Scott, 2001). In addition, beside it confirms the needs of users as suggested by the domain experts during the user requirements' studies (Chapter 5), it has also been able to help the end users (the environmental management team) to identify and explore the requirements and additional features or functions that they may not have thought about earlier. This has been proven through this research when the evaluators had managed to propose an additional of six features for inclusion in future applications. This shows that the

improvement towards the prototype will continue to accommodate the needs of the environmental surveillance activities. Definitely, without the evaluation process, the prototype will be hardened into rigidity.

Furthermore, based on the discussions and the results of the demonstrations and the assessments of environmental management teams, it was found that a usability study is the correct approach to justify and confirm acceptance of the concept in industry. This is because, through the demonstration and evaluation sessions, they were allowed to explore the prototype. Although all of them did not have direct experience in handling a mobile system like ENSOCS (because it is a new approach in the field of environmental management) a large number of them claimed that they have a deep interest in the concepts presented. In fact, they were amazed, satisfied and agreed that this prototype could improve existing environmental surveillance activities. The ENSOCS prototype's capability for remote operations, for accelerating the delivery of information and for improving decision-making capabilities through services and real-time environmental quality monitoring data coincides with the requirements of the industry. A good acceptance by the environmental management teams in both Malaysia and in the UK has shown that the ENSOCS prototype has been developed to take account of current industry standards for field environmental management.

7.9. SUMMARY

This chapter has presented the evaluation process of the prototype application and the results obtained from that process. In brief, the evaluation of functionality through the implementation of Test Cases has shown that the prototype worked well on the devices. All the system requirements were fulfilled, so then it was further evaluated for its usability aspect with practitioners in Malaysia and in the UK.

In Malaysia and the UK, the concept and the prototypes were successfully demonstrated iteratively. As practitioners had opportunities to explore the concept and the prototype, they were able to explore the ease of use of the prototype and identify the usability problems as well as the barriers for implementation of the system. Based on the evaluation feedback, the prototype has undergone refinements on its graphical user interface, on additional data-entry for the inspection checklist and on rearrangement of pages. In addition, the benefits of the prototype concerning the implementation of environmental surveillance have been identified too, through the interviews and through discussions with the evaluators.

This study explores the concept of the use of an Environmental Internet of Things based on the mobile web to help improve communication and the delivery of information in conducting surveillance activities. Various technologies and services such as a digital inspection checklist, real-time environmental monitoring data, wireless sensor networks, weather and traffic information, smartphones functions and others have been included to establish the functions of this system as discussed in Chapter 6. To enhance the capacity of this prototype, the environmental management teams have also suggested that some functions be added to the prototype. Additional functionalities were added and tested except for the function allowing users to conduct Corrective Action and prepare the report corresponds to the issued surveillance report. The function has been added, but the evaluation of it is reserved for future study. The environmental management teams were satisfied and agreed that these functions should and can enhance existing environmental surveillance activities. Therefore, in general, the results are very positive and indicate that the objectives of the evaluation have been achieved.

However, even though the objectives of the evaluation have been achieved, the prototype application should continue to be refined and developed. It should also address the issues of interoperability with other commercial applications so as to meet the expectations of the industry. As these latter issues do not form part of the aims and

objectives of this research, future research to address these issues is definitely needed. The next chapter summarises the research, draws conclusions and makes recommendations for future research.

CHAPTER 8. CONCLUSIONS AND RECOMMENDATIONS

8.1. INTRODUCTION

This chapter summarises the outcomes and achievements of this thesis, as well as recommendations for future research topics that, based on the findings of this thesis, might hold the promise of important results. In order to realise these aims, an overview will be provided by revisiting the research objectives, process and main findings, and these will be discussed critically to evaluate the extent to which the research objectives were met. The evaluation will highlight the limitations and weaknesses which can be improved by future research. This chapter will also discuss the main findings, contributions and achievement of this research. These may provide some ideas for interesting aspects of research questions in the future. At the end of this chapter, a few recommendations for the industry and the research community will also be given.

8.2. REVISION OF THE RESEARCH AIMS AND PROCESS

Within the three selected case studies, this research has adopted a user-centred design (UCD) philosophy to investigate the potential for a mobile environmental information system for environmental surveillance. The user requirements for such a system's development were investigated and the results provided the basis for the development of a functional specification and a prototype. The developed prototype then was demonstrated and the usability aspects were evaluated in the field by practising environmental management teams. The usability test was able to obtain very positive feedback from the intended users.

The outcome from the specific tasks undertaken in this research, with respect to the research aim and objectives, is summarised as follows:

Objective 1: To review the existing practice of environmental surveillance on construction sites.

This research was initiated by reviewing the literature to gain knowledge of the current issues in environmental management in the construction industry particularly on the aspects of environmental checking and corrective action and, subsequently, to identify the research problems and form the research aims and objectives. It was identified that environmental surveillance on construction sites in Malaysia still depend upon pencil and paper notebook for implementation and reporting. Although robust, this method is labour-intensive and time consuming. Moreover, it is dependable on unwieldy tools that can provide only limited sources of information at a particular time. As an environmental management team is usually very busy and confront environmental issues almost on a daily basis, they require concise, to-the-point and timely information which is the directly usable by them in making decisions or formulating actions. Previous research has shown that the new Information and Communication Technologies (ICT) can provide appropriate tools to support the delivery of environmental information amongst an environmental management team. It links the physical world to cyberspace through smart devices which have resulted in more and more smart processes and services which can support environment protection initiatives.

Objective 2: To review mobile environmental information systems, wireless sensor networks, related concepts and enabling information and communication technologies.

The review of the literature and of the technologies relating to environmental information systems, wireless sensor networks and mobile environmental information systems (as presented in Chapter 2) informed the researcher about a number of topics pertinent to the subject of this research. They included the evolution of the environmental information system from a desktop base towards the Internet of Things where the Web was integrated with smart objects including wireless sensor networks. The review also revealed that the tools available to environmental management teams

for environmental surveillance on construction sites are still limited because most of the off-the-shelf commercial products are specifically designed for generic purposes and addressing very specific tasks. Thus, this has revealed the potential for the development of a mobile environmental information system (MEIS) that can cater for the need of the practitioners in the field. However, the development of MEIS requires the system's developers to consider the unique characteristics that are intrinsic to mobile computing such as hardware constraints, operating context and usability requirements.

Objective 3: To investigate the user requirements for the application of a mobile web and for devices for environmental surveillance on construction sites in Malaysia.

This objective has been achieved through the user requirements' studies which involved detailed interviews, a scenario-based design approach and the presentation of the prototype to domain experts in Malaysia. The requirements' studies were carried out in order to obtain a proper understanding of environmental surveillance and its relationship with information technologies. The direct engagement with the domain experts in the field was beneficial and it produced relatively accurate and reliable requirements' information. As presented in Chapter 5, the use of a user-centred design process in the requirements' analysis proved to be effective in obtaining an in-depth understanding of the intended users, their background and, more importantly, their tasks and the operational context of their work. The information collected through these interviews was then analysed and this resulted in the formulation of the system design goals and a conceptual model which then led to the creation of the functional specifications (as presented in Section 5.4). This was followed by the development of the system architecture.

Objective 4: To develop and implement a prototype system of a mobile web for environmental surveillance based on the developed end-user specifications using a combination of ICT tools.

The achievement of objective 3 has led to the creation of functional specifications and the system architecture. This has created a basis for the development of the prototype as discussed in Chapter 6. Subsequently, the implementation of the prototype was carried

out by the installation of a wireless sensor network in a construction project in the United Kingdom and direct interaction with actual fieldworkers in three different case studies (as presented in Chapter 7). The respondents were given an opportunity to use the developed interactive prototype by using a smartphone and providing feedback on the usage. Overall, the prototype demonstrated the feasibility of the concept.

Objective 5: To evaluate the functionality of the developed prototype system of a mobile web for environmental surveillance.

The final objective was achieved through the interactive evaluation of the prototype by environmental management teams at actual construction projects, both in the UK and Malaysia. The test participants were given the prototype to perform the specific tasks given. The time taken in performing each task was recorded and then compared with that of traditional methods. The participants were then interviewed and asked to complete questionnaires that probed their subjective views on the usability of the prototype. Based on the results, the prototype was refined (as presented in Section 7.6). Overall, the qualitative test results were very encouraging. The environmental management teams found the prototype easy to use and, most importantly, it was useful in performing environmental surveillance. They were satisfied and keen to use the application in place of the traditional methods that they are currently using. The construction programme managers seemed enthusiastic and comfortable with the idea and the concept of using a mobile environmental information system via a Smartphone while performing environmental surveillance.

8.3. CONCLUSIONS FROM THE MAIN FINDINGS

The following conclusions can be drawn from the research with respect to the following themes:

8.3.1. THE PROTOTYPE SYSTEM

It is important to emphasise that this research has focused on the concept of capitalising on the advantages of a mobile web and smart objects for environmental surveillance issues on construction sites. The issues of mobile devices as a mediator between people, things and the Internet as well as providing information delivery and sharing, collaboration, a warning alert system, real-time data streaming and end-user programming with a mobile web were addressed accordingly through several user studies. These studies have successfully demonstrated that the integrated mobile web, along with other smart objects like smartphones, wireless sensor networks and weather stations, has the capability to enhance environmental surveillance through the enhancement of information delivery, an alert system and knowledge sharing. The prototype mobile web proved that the concept was achievable, could function in real-time and that it could be evaluated interactively.

In addition, because of the above mentioned achievements, the concept was not only achievable but it was thoroughly accepted by practising environmental management teams. The user studies successfully shared the benefits of the prototype with these teams. The prototype was able to assist the environmental team members in their daily activities. The real-time environmental quality monitoring features, the mobility of the devices, the inspection data collection features, the information and services provided by the prototype itself, have improved their communication, have enabled environmental team members to accomplish their tasks more quickly and have promoted knowledge sharing among them. Hence, it has demonstrated the need for the application of this system in the construction industry.

The demonstrated prototype application also offers some tangible help for future development by web programmers who will be working in this field who are not necessarily specialised in construction environmental management. As the nature of the construction industry, and the management issues and challenges of looking after the

environment on the construction sites themselves, are different to the challenges faced by other industries, web programmers might obtain valuable inputs with regards to understanding the requirements and information needs of a construction environmental management team. The benefits and limitations of the prototype have also been identified (as shown in Section 7.5.2). This, in turn, provides useful information for the developers of mobile applications concerning the appropriate methods and specifications required for the construction industry.

8.3.2. INTERNET OF THINGS (IoT)

The Internet of Things (IoT) is the concept chosen to implement the mobile environmental information system in environmental surveillance on construction sites. There is no doubt that the IoT is still a very new topic in the area of environmental management of construction sites and the research undertaken in this area is still very exploratory or demonstrative in nature. However, the IoT can be seen as an answer or alternative in responding to the disadvantages of current approaches. The IoT infrastructure allows combinations of human beings, sensor technologies, smart objects (i.e., telematic navigation devices, smart cards, etc.), mobile devices technologies and others which can enrich the value of information as those working in this area can discover and explore these aspects and learn to take advantage of each aspects's data by pooling resources and dramatically enhancing the scope and reliability of the resulting services (Vermesan et al., 2011). These arrangements of IoT have enabled more smart processes and services which can support environment protection activities. With the advancement of the Web and smart objects technologies as well as the achievable concept shown in this research, the IoT has been shown to have the potential to expand further to many types of applications in construction environmental management activities.

8.3.3. MOBILE ENVIRONMENTAL INFORMATION SYSTEM

Despite the huge advantages offered by Information and Communication Technologies (ICT), only a few developed commercial applications are applicable to environmental management within the construction industry. As this thesis was being developed alongside the continuing literature review and the technological reviews on the use of

ICT in construction environmental management, it was found that there are a wide range of mobile tools for walk-through inspections and air and noise quality monitoring. However, they are only intended to work separately and focus on very specific tasks. They were developed and designed for generic purposes and address very specific tasks without any integration with many smart objects. Furthermore, they are not really customised for use in construction environmental management. Similarly in the field of Information Systems research, the number of studies that have put an emphasis on ICT in relation to the environmental management of construction activities are minimum. Many of them focused on the implementation of a system to monitor environmental pollution or field data collection.

As discussed in the earlier chapters, generally, the mobile environmental information system (MEIS) as a part of the Internet of Things can be used by environmental team members in their environmental surveillance activities. Changing from the traditional way of doing things which relied on a paper-based system, MEIS enables environmental team members to accomplish their tasks more quickly, expedites the delivery of surveillance reports and promotes knowledge sharing amongst the members. They would also easily obtain related information on projects, environmental sensitive receptors, real-time environmental quality monitoring and other services such as weather and traffic conditions so that they are able to make informed decisions. The MEIS will definitely play an important role here as construction environmental management teams need to be aware of, and have knowledge about, the activities on sites and their impacts on the environment as a means of achieving their strategic goals. This can only be achieved through the use of a mixture of tools, techniques and, most importantly, people, to get the job done.

In addition, the mobile web, one of the main components of MEIS, has always been associated with social networking communication. However, it is important to note that this research has revealed that the experts argued that social networking communication (e.g. Facebook, Twitter, Instagram etc.) are not suitable for conveying environmental data due to confidentiality issues and the restrictions on their usage imposed on workers in the workplace during working hours.

8.4. LIMITATIONS OF THE RESEARCH

The research project had several limitations, as follows:

- Limited numbers of research participants - the limited number of users was due to the small number of environmental experts available during the user requirements study as well as the small number of environmental management team members and environmental expert that willing to participate in the detailed interview, the prototype demonstration and the prototype evaluation.
- Limited number of wireless sensors networks - due to the cost constraint, only one (1) set of wireless sensor networks was purchased for the purposed of this research hence the demonstration and evaluation sessions with the evaluators had to be conducted by using the source of real-time data from a case study in the UK, rather than multiple data sources. Furthermore, it was more economical to place the wireless sensor networks at the case study in the UK due the cost and time constraint as well as difficulty of travelling to Malaysia. These would limit the real-time data for this research. However, the real-time data for this research might be limited but this allowed the researcher to demonstrate that the users can assess the real-time data at anytime from anywhere as long as connected to the network.
- Short period of demonstration and evaluation sessions – this research binds to strict requirements and subject to formal approvals at designated milestones. Thus, the demonstration and evaluation sessions was carried out accordingly. Furthermore, the sessions were depended on the availability of the evaluators involved in this research. However, the demonstration and evaluation sessions still achieved its objective by being able to show the users how the application will function.

8.5. RESEARCH NOVELTY AND CONTRIBUTION

The novel contribution of this research is presented in terms of providing the concept that the use of mobile devices with the integration of a mobile web and various smart objects will provide environmental management teams with a new prototype tool to enhance their decision-making capabilities and will facilitate the managing of their day-to-day activities. As it has been tested in a robust environment (actual construction sites), this research has demonstrated that the prototype can enhance the delivery of data, information and reports as well as enhancing the ability of environmental management teams in making well-informed decisions while performing environmental surveillance on construction sites. This would improve environmental enforcement and, subsequently, enhance the implementation of environmental management on construction sites in Malaysia.

This research also clearly supports the Malaysian construction industry in gauging the success of the Construction Industry Master Plan Malaysia 2006-2015 (CIMP). The mission, as outlined in the CIMP, is for the Malaysian construction industry to be a dynamic, productive and resilient enabling sector supporting sustainable wealth generation and value creation driven by a technologically-pervasive, creative and cohesive construction community (CIDB, 2007). In order to achieve the overall strategic direction, seven strategic thrusts have been developed but Strategic Thrust No. 6 specifically addresses the issues of ICT in the construction industry. Strategic Thrust No. 6 emphasises the leverage on information and communication technology in the construction industry by encouraging knowledge sharing for continuous improvement and developing the local construction software industry (CIDB, 2007). Since the prototype was developed based on the direct requirements from practising construction environmental experts in Malaysia (based on the detailed user studies) and has been evaluated in actual working conditions by both practitioners in Malaysia and UK, therefore, the buy-in from the Malaysian construction players has been considered and knowledge sharing, especially in terms of usability problems and implementation barriers amongst the Malaysian and UK participants, has been achieved.

In addition, the thesis also presents a novel contribution by reviewing and synthesising multiple subject areas and bodies of knowledge. As the development of the prototype was complex, subject areas and bodies of knowledge such as construction

environmental management; mobile computing; information and communication systems; the Internet of Things (IoT); web and wireless sensors programming; web services; wireless communications and geolocation were reviewed and synthesised in an integrated manner. Moreover, in order to accomplish the research the following main activities were carried out: (1) Gaining an understanding of the environmental issues on construction sites and of the existing approaches in addressing those issues; (2) Gaining an understanding of the role of the environmental management team and its information requirements for informed decision-making; (3) Looking at the concept of a mobile environmental information system as applied to the construction industry, since the prototype development was based on the direct requirements from practising environmental experts (based on the preliminary and detailed user studies); (4) The development of the prototype through live computing technology (based on a creative integration of tools and technologies); (5) The testing of the prototype in a real environment, within actual on-going construction projects; (6) The structured evaluation and analysis of the prototype implementation with environmental management teams from the construction industry to validate the concept, and (7) The structured presentation and discussion of the factors that drove and enabled the implementation of the concept, as well as any implementation difficulties. Therefore, the development and implementation of the prototype benefited from different theoretical lenses and technologies.

Finally, one of the strength of the Design Science Research is rely on its epistemology of “knowing through making”. Obviously, this research integrate for the first time the mobile devices, web and the smart objects for the purpose of providing environmental management team on construction sites with more effective means of averting the environmental pollution. This is in line with the aims of the Design Science Research which is to “produce and apply knowledge of tasks or situations in order to create effective artefacts” in order to improve practice (March and Smith, 1995). As a result, this research had managed to produce a totally new mobile environmental information system as a part of Internet of Things technologies for environmental surveillance. Along the process, this research had managed to identify sufficient number of, and suitable functions on the system. One of the important contributions is that the evaluators were managed to spot the lacking; in terms of the system to receive and respond which has not been discovered during the user requirement studies, thus it

deems to be important in enhancing the ability of prototype to support the environmental surveillance. Additionally, through the evaluation process in this research, it was found that the work procedures and the attitude of the workers towards adoption of the new technologies would not be easily changed in order to facilitate the implementation of the system. Furthermore, as a profit oriented entity, the construction company is very critical about the return of investment and the operational cost. These very important issues were only being discovered through direct engagements with the construction players during the evaluation stage. Thus, this research provides useful information for the developers of mobile applications concerning the appropriate methods and specifications for the construction industry. From this research they would obtain valuable input with regards to understanding the requirements and information needs of construction environmental management teams as well as the benefits and limitations of the prototype. These would offer some tangible help for future development by web programmers who are not necessarily specialised in construction environmental management so that it would assist in making it easier for them to manage the whole development process.

8.6. RECOMMENDATIONS

The research has established a prototype system that was proven in concept and was technically viable and accepted by practitioners at the three selected case studies. During the implementation period, the researcher had to get up-to-date with the research and literature in the field of the Internet of Things and faced challenges to prove the knowledge gaps in construction environmental management, in the concept, and in the need to develop a high-level prototype system. Meanwhile, as the research progressed, some of the answers to the most pertinent problems were found and a few opportunities for future research were identified. These may serve to guide future research in both field of the academics and industries.

8.6.1. RECOMMENDATIONS ON THE AREAS FOR FUTURE STUDIES

Despite the Internet of Things in general or Mobile Environmental Information Systems (MEIS) in particular, applicability in many research areas, they are considered as new topic in construction. The area looked at by this research, therefore, could be expanded to other research areas within the construction sector such as construction disaster management, environmental resource management, construction waste management, mobile applications and human-computer interaction. The ENSOCS prototype could be more refined, redeveloped and integrated with other applications so that the capabilities and the functions of it could be enhanced in order to accommodate new research areas. Therefore, an exploration of new additional functions and features that would add value to the ENSOCS prototype while meeting the expectations of the industry, in addition to the potential follow-up research work on the integration issues of ENSOCS prototype with other existing applications, would be significant issues to explore. Because ‘‘prevention is always better than cure’’, there is a need to identify potentials and to manage environmental impacts as early as possible regardless of the size and scale of project (Nikander & Eloranta, 1997, cited in (Cheung et al., 2004). However, there are still many organisations that make critical business decisions without access to the right data at the right level of accuracy, relying on judgement and ‘best guess’ (Fathi, 2009). Therefore, a mobile environmental information system would play an important role as a surveillance tool that comes additionally with a decision-support tool providing enriched data and information, and walk-through inspection notes for environmental management teams.

This thesis has also identified cost as one of the implementation barriers. As the return on investment (ROI) is a main concern of the respondents, it is recommended that future research should incorporate a financial study. Financial issues like additional cost affecting the company e.g. the cost of acquisition, operation, maintenance etc. as well as the break-even period needs to be studied to prove that their investment is economically feasible. In addition, it is also recommended that long-term usability studies with large user groups be performed so that the impacts of the prototype on organisations as well as on environmental compliance rates could be demonstrated further. Long-term usability studies could also address the concern on maintenance costs in the long-run. All this is needed to prove that these tools are not just able to bring increased efficiency

to the entire construction environmental management process but also that they will provide value for money.

8.6.2. GENERAL RECOMMENDATIONS FOR THE INDUSTRY

The construction industry in the twenty-first century is a globalized industry and is very different from what it was in the past. According to Ahmad et al. (2010), the main change-agents in the construction industry in twenty-first century are the growing use of ICT and the increasing extent of globalization. In addition, the building industry is under pressure to provide value for money, sustainable design and construction, etc. (Arayici et al., 2011). Globalization urges construction players to be more competitive and to comply with more stringent requirements from environment-related statutes, regulations, codes and general policies that influence the operation of construction companies, impacting on how constructed structures are situated, the way they are planned and designed, the materials and equipment used, the procedures and technology adopted, and how the finished facilities are maintained, re-structured and, ultimately, demolished. All these requirements mean that ICT plays an important role in supporting tasks, easing communication barriers, speeding up processes and response times, managing information and many more undertakings (Jaafar et al., 2007a, Bowden et al., 2006, Peansupap and Walker, 2005).

However, as has been mentioned earlier, ICT adaptation among construction players is high in the design phase and in facility management while the use of ICT by contractors and site workers is surprisingly low (Löfgren, 2007). They tend to simply view ICT as a tool to support processes in construction (Ahuja et al., 2009, Ahmad et al., 2010). Thus, this situation ends up with the construction players continuing to adopt off-the-shelf commercial products without a detailed understanding about user requirements and the contexts in which these systems will be used (Aziz et al., 2009a).

Therefore, a shifting of paradigm among construction players is needed. Ahmad et al. (2010) suggest that the integration of informational, organizational and contractual within the construction industry will have to come together for the development and IT adaptation among the construction organizations in this era. In addition, it is also encouraging to obtain more involvement from construction personnel during the development of any applicable ICT application. It is well acknowledged that

construction personnel are busy and work in a dynamic, competitive and ever-changing environment, but their knowledge and experience are really important in the development of any ICT application.

8.7. CONCLUDING REMARKS

The ENSOCS prototype application carries the vision of the “Internet of Things” where environmental and daily life items become part of the Internet. With the smartphone playing a role as intermediary between environmental management teams, ‘things’ (wireless sensor networks and a weather station) and the Internet (www.ensocs.net), the interactions between them will be able to provide speedy information, enhanced delivery of reports, improved work performance and alerts on events of environmental non-compliances. These will be particularly important as a surveillance tool that helps construction environmental management teams to perform surveillance activities and make informed decisions in the light of awareness of the current status of environmental compliance of the project and other related information through the surveillance report and real-time environmental quality monitoring data, traffic information and the weather conditions at any time and any place while connected to the network.

The ENSOCS prototype was developed based on a construction environmental management methodology with direct engagement from practitioners on actual construction sites. It then was blended together with other multiple subject areas and bodies of knowledge such as mobile computing; information and communication systems; the Internet of Things (IoT); web and wireless sensors programming; web services; wireless communications and geolocation, in an integrated manner. The ENSOCS prototype then underwent demonstration and evaluation with environmental management teams as evaluators at three selected case studies in the UK and Malaysia. This testing exercise was critical in order to prove the concept and receive acceptance from practitioners in the field. The evaluators provided significant input by raising quality or reliability issues while also finding and asking for the removal of errors from the system. While this input helped the researcher to protect the users from any negative impacts of such a system, it also managed to establish some degree of confidence that

the programme 'does what it is supposed to do and does not do what it is not supposed to do'.

In conclusion, the ENSOCS prototype can play an important role in the advancement of The Internet of Things and in the adoption of mobile applications by the construction industry specifically in the area of environmental management. One of the main contributions of this research is that the concept was proved and potentially accepted by the industry. This provides an opportunity to expand and continue research into this subject in the future. Three topics that might complement this effort is taking into account the possibility of integration with a commercial system, a study on the return of investment and the development of a generic system. By working further in this particular area it might be possible to encourage and help the industry to adopt this concept. Thus, the industry will be able to exploit current information technologies to encourage the future further integration of the construction industry.

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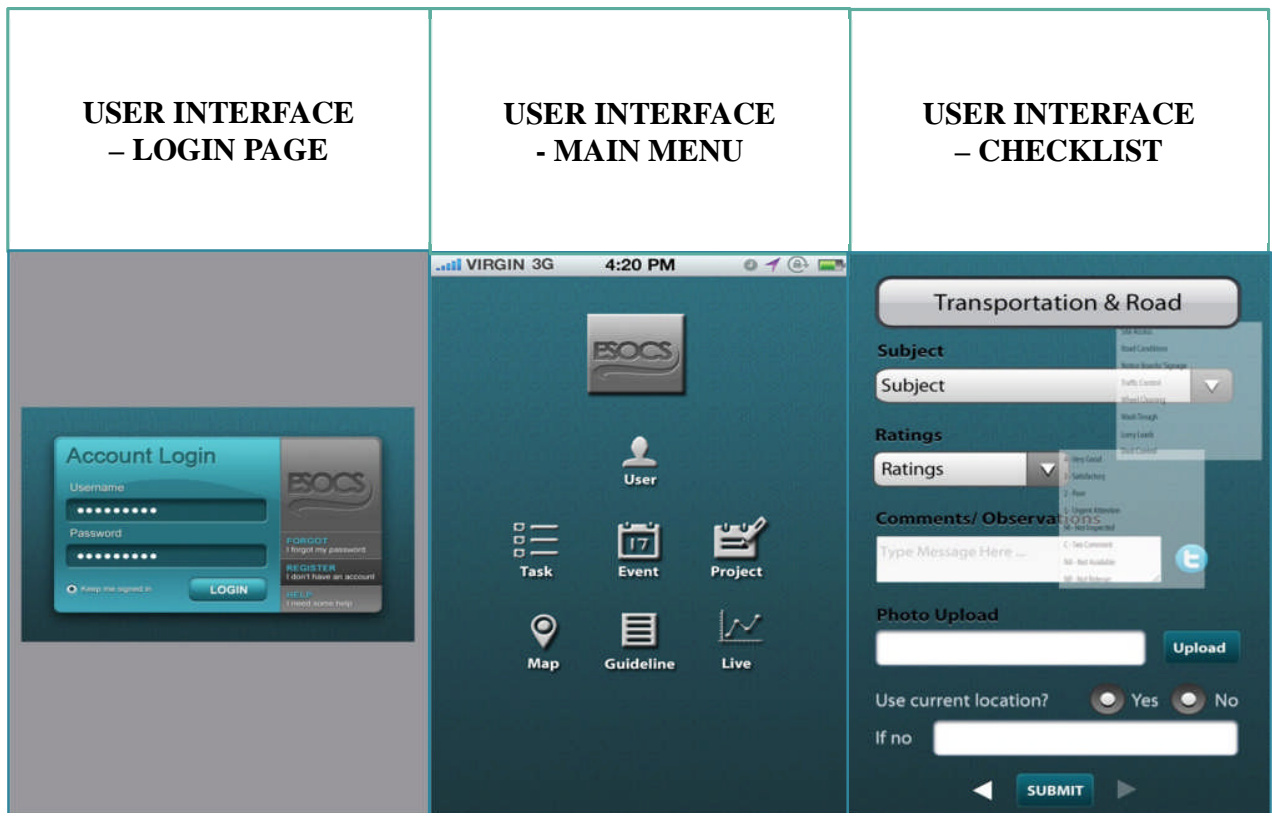
APPENDIX 1



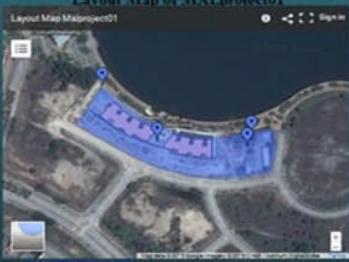




LIST OF CONSTRUCTION ENVIRONMENTAL MANAGEMENT PLAN

1. Construction Environmental Management Plan of Phase 3 City Vizion in Bristol, United Kingdom.
2. Construction Environmental Management Plan for the Proposed Development of Plymouth EfW CHP Facility in Plymouth, United Kingdom.
3. Construction Environmental Management Plan (CEMP) for the proposed Aerohub Business Park at Newquay Cornwall Airport in Cornwall, United Kingdom.
4. Construction Environmental Management Plan for Heslington East in York, United Kingdom.
5. Construction Environmental Management Plan (CEMP) for the Proposed Development of North West Cambridge in Hampshire, United Kingdom.
6. Construction Phase Environmental Management Plan of the Proposed Development of Newfoundland, Canary Wharf in London, United Kingdom.
7. Construction Environmental Management Plan (CEMP) for the Proposed Development of GSK Biopharmaceutical Production Facility in Ulverston, United Kingdom.
8. Environmental Management Compliance Plan (EMCP) for the Proposed Development of Taman Selatan Precinct 5, Putrajaya, Malaysia.
9. Environmental Management Plan (EMP) for the Proposed Development of Package DPT002 (Kajang Depo), Selangor, Malaysia.
10. Environmental Management Compliance Plan (EMCP) for the Proposed Development of Taman Selatan Precinct 5, Putrajaya, Malaysia.
11. Environmental Management Compliance Plan (EMCP) for the Proposed Earthworks for Parcel Z, Putrajaya, Malaysia.
12. Environmental Management Compliance Plan (EMCP) for the Proposed Development of Lot 2G3 & 2G4, Precinct 2, Putrajaya, Malaysia.
13. Environmental Management Compliance Plan (EMCP) for the Proposed Development of Istana Selangor, Precinct 8, Putrajaya, Malaysia.
14. Environmental Management Compliance Plan (EMCP) for the Proposed Development of Bridge 9 (BR9), Putrajaya, Malaysia.
15. Environmental Management Compliance Plan (EMCP) for the Proposed Earthworks for Precinct 18, Putrajaya, Malaysia.

APPENDIX 2

LOW-FIDELITY PROTOTYPE



<p align="center">USER INTERFACE – BEST PRACTICES</p>	<p align="center">USER INTERFACE – ENVIRONMENTAL SENSITIVE AREAS</p>	<p align="center">USER INTERFACE – REAL-TIME MONITORING DATA</p>
<div align="center">  <p>BEST PRACTICES</p> </div> <hr/> <p>Title: Sediment control – silt trap and fence.</p> <p>Objective: To control water pollution by reducing the quantity of contaminated water from entering the waterways.</p> <p>Plan: • Development in phases • Design appropriate erosion and sediment control measures e.g. silt traps, silt fences, sediment ponds or any other effective treatment whichever appropriate to predicted stormwater</p>	<div align="center">  <p>Layout Map of MALproject01</p>  </div> <div align="center">     </div>	<div style="background-color: #cccccc; padding: 10px;"> <p>Frame Number170 SensorBAT Value47 Frame Number170 SensorDust Value0 Frame Number170 SensorMCP Value60</p> </div> <hr style="border-top: 1px dashed black;"/> <p>Legends:</p> <p>MCP : Microphone (Sound)</p>

APPENDIX 3

QUESTIONNAIRES AND INTERVIEW QUESTIONS (USER REQUIREMENTS)

REF:

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**THE APPLICATION OF MOBILE
WEB AND DEVICES FOR
ENVIRONMENTAL
SURVEILLANCE ON
CONSTRUCTION SITES IN
MALAYSIA**

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This questionnaire will be used purely for the purpose of academic research. All responses will be treated in strict confidence.

Questionnaire: User Requirement Study for the Development of the Proposed Prototype of Mobile Web for Environmental Surveillance on Construction Sites (ENSOCs)

Introduction

The objective of the interview is to investigate the system and information requirements of environmental professionals for the development of the proposed prototype of mobile web that later to be known as ENSOCs at www.ensocs.com. The Web will be designed and developed for internet browsing via smartphone. It would work together with telemetry sensors to provide the real-time environmental data monitoring while the officer carry out the environmental surveillance.

It is anticipated that the Web would improve environmental checking and correction process by providing a tool for environmental enforcement offices for managing their environmental surveillance activities and enhance their decision-making capabilities.

Definition and Concept of Environmental Surveillance

Environmental checking and correction is designed to support emergency response activities in the event of unexpected changes; check whether statutory regulations are complied with; provide information for systems control or management; and provide recommendations to the project proponent for improving their environmental monitoring programs ([Barrow 2002](#)). Apart from a few techniques, it can be done through an environmental surveillance where the professionals carry out routine physical inspection or patrolling, and/or performs observation through an established multi-media network on and around the construction site ([Tasaki, Kawahata et al. 2007](#)). This generates information that is derived from observation of human and construction activities on site, conditions of mitigation measures and others in order to supplement the findings of environmental quality

monitoring programmes. And these can be used to form a holistic performance evaluation towards continuous environmental management at the construction site.

These tasks however, certainly are time consuming and challenging using the traditional method ([Vivoni and Camilli 2003](#)). It is very common in the traditional method where the environmental personnel rely on paper based checklist, plans and manuals during environmental surveillance and auditing. These documents however, are difficult to carry in big quantities and offers very limited source of information at a particular time. Most importantly, due to its nature it is often unable to react to a rapidly changing context and fails to demonstrate the interrelationship between the activities and their consequences in timely manner. Moreover, the traditional paper based method is labor-intensive, susceptible to georeferencing errors and exposed to deficiencies and discrepancies ([Vivoni and Camilli 2003](#); [Kim, Oh et al. 2008](#)).

In the context of environmental monitoring, traditional method is referring to the environmental grab sampling techniques. For water quality monitoring for example, water samples for suspended solids measurement should be collected in high density polythene bottles, packed in ice (cooled at 4°C without being frozen), and delivered to the laboratory as soon as possible after collection for analysis and interpretation. Whereas for noise quality monitoring, data will be collected via sound level meter and stored in the data logger. The sampled data in the data logger then will be uploaded into the system at the laboratory by using the diskette or any other temporary data storage devices before the analysis to be carried out. For this method, handling and delivery of sample, distance between monitoring field and laboratory, and collection procedures itself are very crucial.

In contrast to the traditional paper based method, the usage of mobile devices and real-time data streaming through web-based systems has the potential to enhance information management and communication processes among participants and play an important role in field data acquisition and validation (Pundt 2002), detecting the potential environmental impacts ([Xiang-zheng, Ji-yuan et al. 2002](#)) and more importantly, provides a warning sign to areas of construction activities that require immediate corrective action ([Cheung, Cheung et al. 2004](#)). The ability to identify potential environmental impacts as early as possible is vital to a project of any size and scale because “prevention is always better than cure” (Nikander & Eloranta, 1997 cited in ([Cheung, Cheung et al. 2004](#))). Environmental professionals can easily carry mobile devices with wireless communication connection to field locations for their data collection and validation tasks. They can easily retrieve data and information from the web servers and/or perform real-time data updates, exchanges data between those servers and receive a warning sign alert from the environmental sensor at their mobile devices if any, simultaneously.

Questionnaire

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

General Instructions: Please answer all questions.

Part 1: Background Information

1. Name of Company: _____
2. Address: _____
3. Telephone Number: _____
4. Current Designation: _____
5. Age: _____
6. Sex: M | F
7. Years of experience in the construction industry: _____ years
8. Length of experience as a
 - a. Project Manager: _____ years
 - b. Environmental Site Representative: _____ years
 - c. Environmental Manager: _____ years
 - d. Environmental Executive/Engineer: _____ years
9. How long have you been employed as a environmental professionals in your present firm: _____ years
10. How many projects do you manage at a time? _____
11. Numbers of environmental professionals that currently are reporting to you? _____

Part 2: Environmental Management Tools

1. Have you used any Information Communication and Technology (ICT) system application to support your checking and corrective action exercise? Y| N | Not sure
 - a. If Yes, please answer the questions as below.
 - i. The name of the sites/url (www.): _____
 - ii. Purpose: _____
 - iii. How effective are they?
 - iv. What are their limitations?
 - v. What features do you most frequently used? Why?
2. What other tools/aide-memoirs (IT/non-IT) do you use as you perform the Environmental Checking and Correcting Action? Y| N | Not sure
 - a. If Yes, please answer the questions as below.
 - i. The name: _____
 - ii. Purpose: _____
 - iii. How effective are they?
 - iv. What are their limitations?
 - v. What features do you most frequently used? Why?
3. Please indicate how many hours are required for you to prepare and submit the report of environment surveillance to your upper level in the current situation? Starting from arriving at site and ends with submission of the hardcopy report. _____ hours
4. Please indicate how many hours are required for you to get the environmental monitoring data in the current situation? Beginning with starting time at site and ends with receiving of the final result. _____ hours
5. If there was one new killer ICT application specifically for Environmental Checking and Correcting Action, which features would you like it to have?

Part 3: Key Issues

1. Information Requirements
 - a. Could you list four (4) of your most important tasks that related to Environmental Surveillance?
 - b. What is the information that you needs to deliver each task effectively?
 - c. What are the other key items of information required in managing your day-to-day activities as an Environmental Professional?
 - d. What project and environmental management related information are required?
 - e. What information is required in real-time (i.e. as it occurs)?
 - f. What is the frequency of the info that you require? (daily or monthly)
2. Services Requirements
 - a. What external services (e.g. weather information) would you like delivered to you in real time?
 - b. Do you think that automatic pop-ups or alerts e.g. tweeter could help to convey the message regarding the environmental status?

Part 4: Scenarios for Designing Web Sites

Scenario 1: Carry out an environmental inspection on selected construction site for the first time.

1. Task: Find the relevant environmental sensitive receptors and potential source of pollutions which associated with the said construction site.
2. Information required: Details on site and his surrounding area location and conditions.
3. Current information/service delivery: paper-based or electronic (static mode) of inspection checklists, site layout plan(s), land use plan(s), internal environmental policies, procedures and guidelines. An environmental manager is to review those reports and get all relevant information.

Scenario 2: At the construction site, you have spotted that oil containers were placed on the bare ground and oil spill was spotted on the ground.

1. Task: Provide a report of the non-compliance (storage of fuel, chemicals and dangerous goods) and share the findings on the twitter.
2. Information required: Location of the spillage, type of liquid spillage and photos of the source of spillage.
3. Current information/service delivery: paper-based or electronic (static mode) of inspection checklists, site layout plan(s), Global Positioning System (GPS) unit, time clock and camera. An environmental manager is to write down his observation, date and time in the checklist by accompanied with the photos as an evidence.

Scenario 3: Pretend that you are new to environmental inspection on a construction site, and not very familiar with the best practice of sedimentation control.

1. Task: Find out the best practice of sedimentation control and the important areas to focus during the site inspection particularly on sedimentation control.
2. Information required: gain real-time visibility of the status of all environmental checking and corrective action interdependencies, history and progress.
3. Current information delivery: paper-based or electronic (static mode) of environmental guidelines and previous environmental monitoring and audit report done by others.

Scenario 4: Pretend you are now attending an environmental meeting at site office, and you are required to update your upper level on the status of environmental checking and corrective action.

1. Task: Retrieve all the relevant previous inspection reports and obtain the real-time environmental monitoring data.
2. Information required: gain real-time visibility of the status of all environmental checking and corrective action interdependencies, history and progress.
3. Current information delivery: paper based of environmental monitoring and audit (EMAR) reports, construction progress reports and Daily Logs.

Assuming that you have access to a mobile web for environmental checking and corrective action,

- a. What features and functions would you like to have (in your role as Environmental Manager)?
- b. What features and functions do you require to enable you make fast and accurate decisions in your day-to-day activities?
- c. What functions do you require to establish and maintain overall control of the environmental checking and corrective action programme?
- d. Will this type of application improve environmental checking and corrective action efficiency? and if so in what ways – If not, why not?
- e. Do you see any potential for this type of application in environmental checking and corrective action?
- f. From 1 to 5, how effective would you rate the application?

Closing Question

Are you aware of any other Information Communication and Technology (ICT) system applications that can be to support your checking and corrective action exercise?

APPENDIX 4

QUESTIONNAIRES AND INTERVIEW QUESTIONS (PROTOTYPE DEMONSTRATION AND EVALUATION)

REF:

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THE APPLICATION OF MOBILE WEB AND DEVICES FOR ENVIRONMENTAL SURVEILLANCE ON CONSTRUCTION SITES IN MALAYSIA

Name of Researcher:

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This questionnaire will be used purely for the purpose of academic research. All responses will be treated in strict confidence.

Title: Demonstration and Evaluation of the Developed Prototype of Mobile Web for Environmental Surveillance on Construction Sites (ENSOCS)

Introduction

The objective of the session is to demonstrate and evaluate the developed prototype of mobile web for Environmental Surveillance on Construction Sites at www.ensocs.net. Better known as ENSOCS, it was developed with the spirit to improve environmental checking and correction process by providing a tool for environmental enforcement offices for managing their environmental surveillance activities and enhance their decision-making capabilities.

ENSOCS is a web that was specifically designed for internet browsing via smartphone. It works together with telemetry sensors to provide the real-time environmental data monitoring while the officer carry out the environmental surveillance. It would demonstrate the interrelationship between the activities and pollution in the new way as compared to the conventional paper-based method. While maintaining the concept of checklist, users may take a note of their environmental observation using forms in the ENSOCS. For the certain environmental aspects like air and noise pollution, users could confirm their observation findings by referring to the data transmitted by telemetry sensors in real time. In addition, ENSOCS is integrating the knowledge based system by providing a digital format of best environmental practices as one of the main functions.

Usability Study - Heuristic Evaluation

Usability study is a process to evaluate the degree of usability of an interactive system against the specific usability criteria. It is to ensure that the system is well adapted by the users, their tasks and most importantly avoid any negative outcomes from the usage of this system.

Risks and discomforts

The researchers have taken steps to minimize the risks of this study. Even so, you may still experience some risks related to your participation, even when the researchers are careful to avoid them. These risks may include the following: Fatigue from looking at a smartphone screen for approximately 30 minutes and anxiety from displaying your web browsing skills to other people.

Confidentiality

We plan to provide a report detailing the results of this study as part of research findings, but will not include any information that would identify you. There are some reasons why people other than the researchers may need to see information you provided as part of the study. To keep your information safe, we will be using alias for you and your construction project (e.g. User 01 and project 01) and the match from alias to actual person will be only known by members of our team.

Voluntary nature of the study

Participating in this study is completely voluntary. Even if you decide to participate now, you may change your mind and stop at any time. If you decide to withdraw early, your data will be erased.

Contact information

If you have questions about this research, you may liaise with me personally or contact my research supervisor. My contact number is (+44)7857695249 or (+60)1137972784 and my email is a.n.harun@edu.salford.ac.uk. My research is supervised by Professor Erik Bichard, email E.Bichard@salford.ac.uk.

Pre-Test Questionnaire

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

Background Information

1. Name of Company: _____
2. Address: _____
3. Telephone Number: _____
4. Current Designation: _____
5. Age: _____
6. Sex: M | F
7. Years of experience in the construction industry: _____ years
8. Length of experience as a
 - a. Project Manager: _____ years
 - b. Environmental Site Representative: _____ years
 - c. Environmental Manager: _____ years
 - d. Environmental Executive/Engineer: _____ years
9. How long have you been employed as a environmental professionals in your present firm: _____ years
10. How many projects do you manage at a time? _____
11. Numbers of environmental professionals that currently are reporting to you? _____

ENSOCS web in summary

Website URL: www.ensocs.net

First Page: www.ensocs.net

The screenshot shows the University of Salford logo at the top. Below it, there is a form with two input fields: 'Unique ID:' and 'Authorization Code:'. A 'Login' button is positioned below the second field. Underneath the form, there is a section titled 'DESCRIPTION OF RESEARCH' containing the following text: 'Name of Student: Aizul Nahar Harun', 'Supervision by: Prof. Erik Bichard', 'Phd Research Title: The Application of Mobile Web and Devices for Environmental Surveillance on Construction Sites in Malaysia.', and 'Research Institution : The University of Salford, United Kingdom.'

Please key-in the Unique ID and Authorization code as in the boxes as below.

Unique ID

Authorization Code

Second Page:

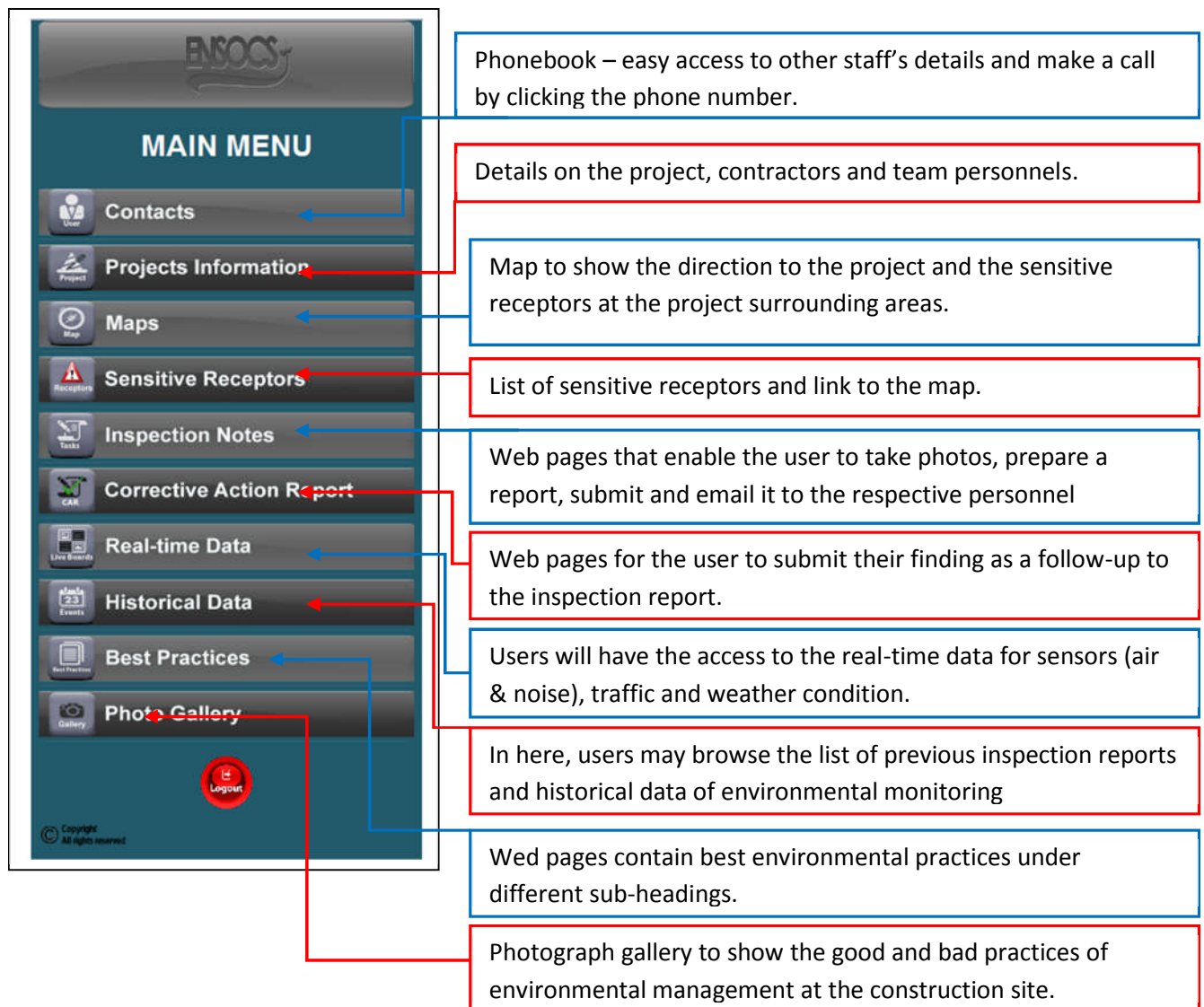
The screenshot shows the ENSOCS logo at the top. Below it, there is a section titled 'ACCOUNT LOGIN'. This section contains two input fields: 'Username:' and 'Password:'. A 'LOGIN' button is located below the password field. At the bottom of the login section, there are three links: 'FORGOT I forgot my password', 'REGISTER I don't have any account', and 'HELP I need some help'. A copyright notice is visible at the very bottom.

Please key-in the Username and Password as in the boxes as below.

Username

Password

Main Menu:



Task Scripts

1. Pretend that you are new to environmental inspection on a construction site, and not very familiar with the best practice of sedimentation control. Find out the best practice of sedimentation control and the important areas to emphasis during the site inspection particularly on sedimentation control. Please write down the first three sentences under the heading of “Check”.
2. You would like to carry out an environmental inspection on selected construction site for the first time, and are wondering what are the surrounding environmental sensitive receptors and potential source of pollutions from the activities on site. Find and write down the list of environmental sensitive receptors which associated with the said construction site.
3. Pretend you are now attending an environmental meeting at the site office, and you are required to update your management on the status of the environmental checking and corrective action. Retrieve all the relevant previous inspection reports and obtain real-time environmental monitoring data. Please write down the date, reference number and the subject of the latest inspection report. Next, write down the frame number and MCP value for the real-time environmental monitoring data.
4. At the construction site, you have spotted that oil containers are placed on the bare ground and oil spill has been spotted on the ground. Take a photo of this non-compliance using your smartphone. Then by browsing the ENSOCS web through your smartphone, prepare the report by inserting this finding into the Web, provide other relevant information to support this finding, and submit and review the report.
5. Email the report as in Task 4 to the relevant authorised person.
6. Update the report as in Task 4 by uploading and attaching the photograph to the report.

Logging Form for Usability Testing

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

Task 1	Pretend that you are new to environmental inspection on a construction site, and not very familiar with the best practice of sedimentation control. Find out the best practice of sedimentation control and the important areas to emphasis during the site inspection particularly on sedimentation control. Please write down the first three sentences under the heading of "Check".
Successful Completion of Task	Yes No
Start Time	
End Time	
Answer	1. 2. 3
Points of Difficulty	
Quotes/Notes	

Name of participant :

Signature :

Date :

Logging Form for Usability Testing

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

Task 2	You would like to carry out an environmental inspection on selected construction site for the first time, and are wondering what are the surrounding environmental sensitive receptors and potential source of pollutions from the activities on site. Find and write down the list of environmental sensitive receptors which associated with the said construction site.
Successful Completion of Task	Yes No
Start Time	
End Time	
Answer	List of sensitive receptors surrounding the project:
Points of Difficulty	
Quotes/Notes	

Name of participant :

Signature :

Date :

Logging Form for Usability Testing

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

Task 3	Pretend you are now attending an environmental meeting at site office, and you are required to update your upper level on the status of environmental checking and corrective action. Retrieve all the relevant previous inspection reports and obtain the real-time environmental monitoring data Please write down the date, reference number and the subject of the latest inspection report. And next, write down the frame number and MCP value for the real-time environmental monitoring data.
Successful Completion of Task	Yes No
Start Time	
End Time	
Answer	<p>Latest inspection report Date: Reference Number: Subject:</p> <p>Real-time environmental monitoring data Time: Frame Number: MCP Value:</p>
Points of Difficulty	
Quotes/Notes	

Name of participant :

Signature :

Date :

Logging Form for Usability Testing

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

Task 4	Prepare the report and review it.
Successful Completion of Task	Yes No
Start Time	
End Time	
Points of Difficulty	
Quotes/Notes	

Name of participant :

Signature :

Date :

Logging Form for Usability Testing

Moderator's initials: _____ Note taker's initials: _____ Research Participant Code: _____

Date: _____

Task 5	Email the finding as in Task 4 to the relevant authorised person.
Successful Completion of Task	Yes No
Start Time	
End Time	
Answer	The mail was sent successfully to
Points of Difficulty	
Quotes/Notes	

Name of participant :

Signature :

Date :

Logging Form for Usability Testing

Moderator's initials: _____

Note taker's initials: _____

Research Participant Code: _____

Date: _____

Task 6	Update the report as in Task 4 by uploading and attach the photograph to the report.
Successful Completion of Task	Yes No
Start Time	
End Time	
Points of Difficulty	
Quotes/Notes	

Name of participant :

Signature :

Date :

Post-Test Questionnaire

Moderator's initials: _____

Note taker's initials: _____

Research Participant Code: _____

Date: _____

1. For each of the following statements, please indicate the degree to which you agree or disagree with the following statements.

	Strongly Agree (0)	Agree (1)	Neutral (2)	Disagree (3)	Strongly Disagree (4)
This site is easy to navigate	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The information was generally where I expected to find it	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It is clear which pages have the information I need about the best environmental practices	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I always know where I am on the site	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I was confident that I would be able to find the information needed to complete the task	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It was easy to learn how to perform new tasks on the site	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. What would make these tasks easier to perform?

3. Has the use of ESOCS web improved communications among the professional involved?

4. How have you and/or your organisation overcome administrative and legal issues associated with using electronic as opposed to traditional methods of communication?

5. How the ENSOCS web with support of telemetry sensors can benefit the environmental surveillance on construction sites in terms of performing the tasks and reporting?

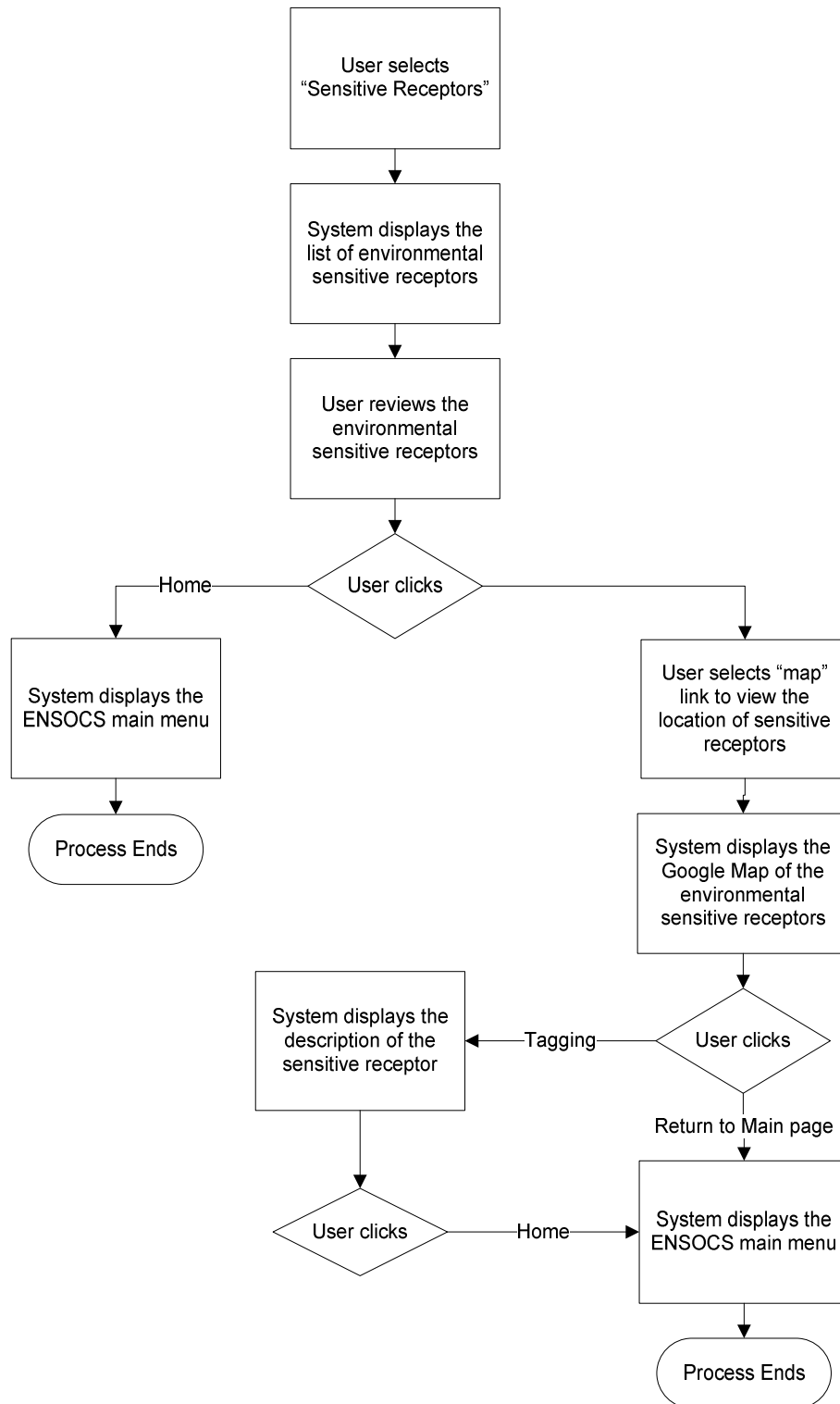
6. Could you please discuss the anticipated barriers for you and your company to adopt this type of Information Communication and Technology (ICT) tools for the same purposes?

7. Do you have any other comments or suggestions?

APPENDIX 5

USE CASE

Use Case: Environmental Sensitive Receptors of ENSOCS



Use Case Description:

This use case describes the process of a user to obtain the information pertaining to the environmental sensitive receptors surrounding the project site. User is allowed to view the list of environmental sensitive receptors with an option to have a view of their locations in the GoogleMap.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the list of environmental sensitive receptors.
2. System displays the view of environmental sensitive receptors in the GoogleMap.

Flow of Events :

1. User clicks on “Sensitive Receptors” icon.
2. System displays the webpage which contains list of environmental sensitive receptors.
3. User clicks on “view map” link.
4. The Google Map with the tagging of environmental sensitive receptors is displayed.
5. User clicks on each tagging.
6. The Google Map displays the detail information about the environmental sensitive receptors.
7. Use case ends.

Alternative Flow of Events E1:

1. Process commence from Step 2 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

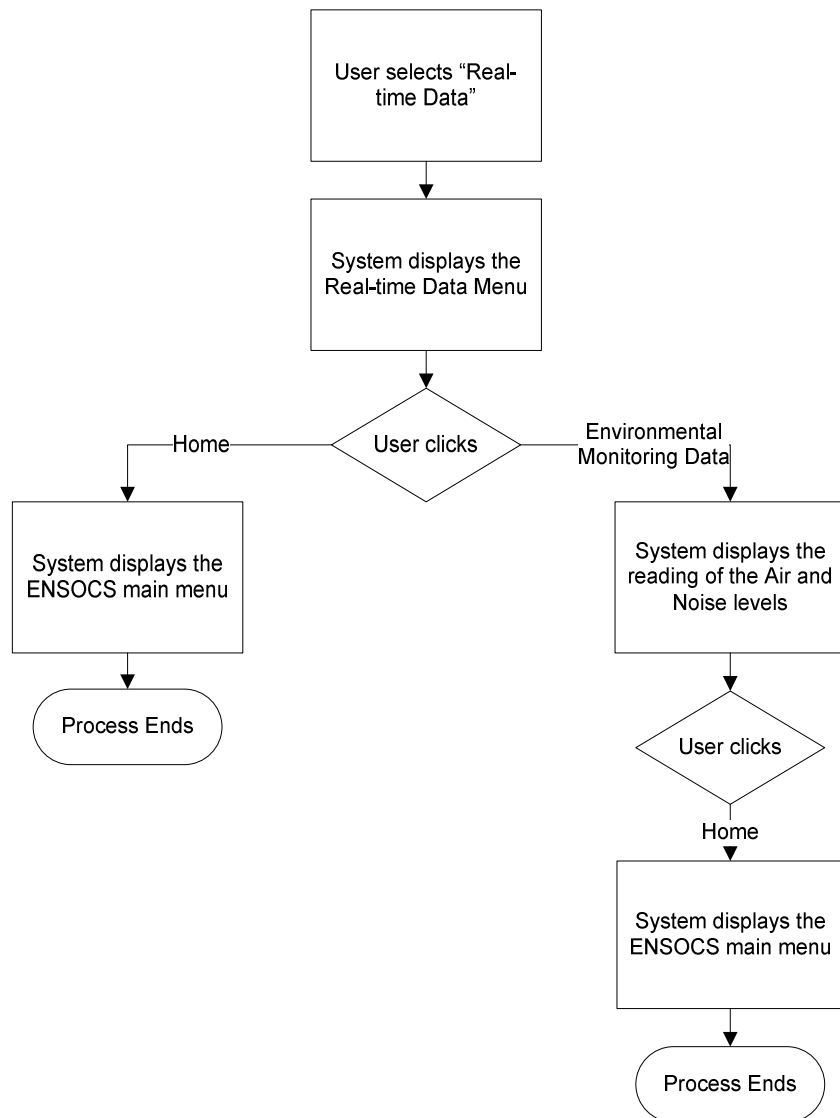
Alternative Flow of Events E2:

1. Process commence from Step 4 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Exceptional Flow of Events :

None

Use Case: Real-time Environmental Monitoring Data of ENSOCS



Use Case Description:

This use case describes the process of a user to obtain the real-time air and noise monitoring data gathered from the wireless sensor network on site.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the reading of the PM₁₀ and Noise level in real-time.

Flow of Events :

1. User clicks on “Real-time Data” icon.
2. System displays the webpage which contains the features as follows:
 - a. Environmental Monitoring Data
 - b. Weather
 - c. Traffic Updates
 - d. Weather Desktop Version
 - e. Air Pollution Index (API)
3. User clicks on “Environmental Monitoring Data” icon.
4. System displays the real-time data of the PM₁₀ and Noise level.
5. User clicks “Home” button.
6. System displays the ENSOCS main menu.
7. Use case ends.

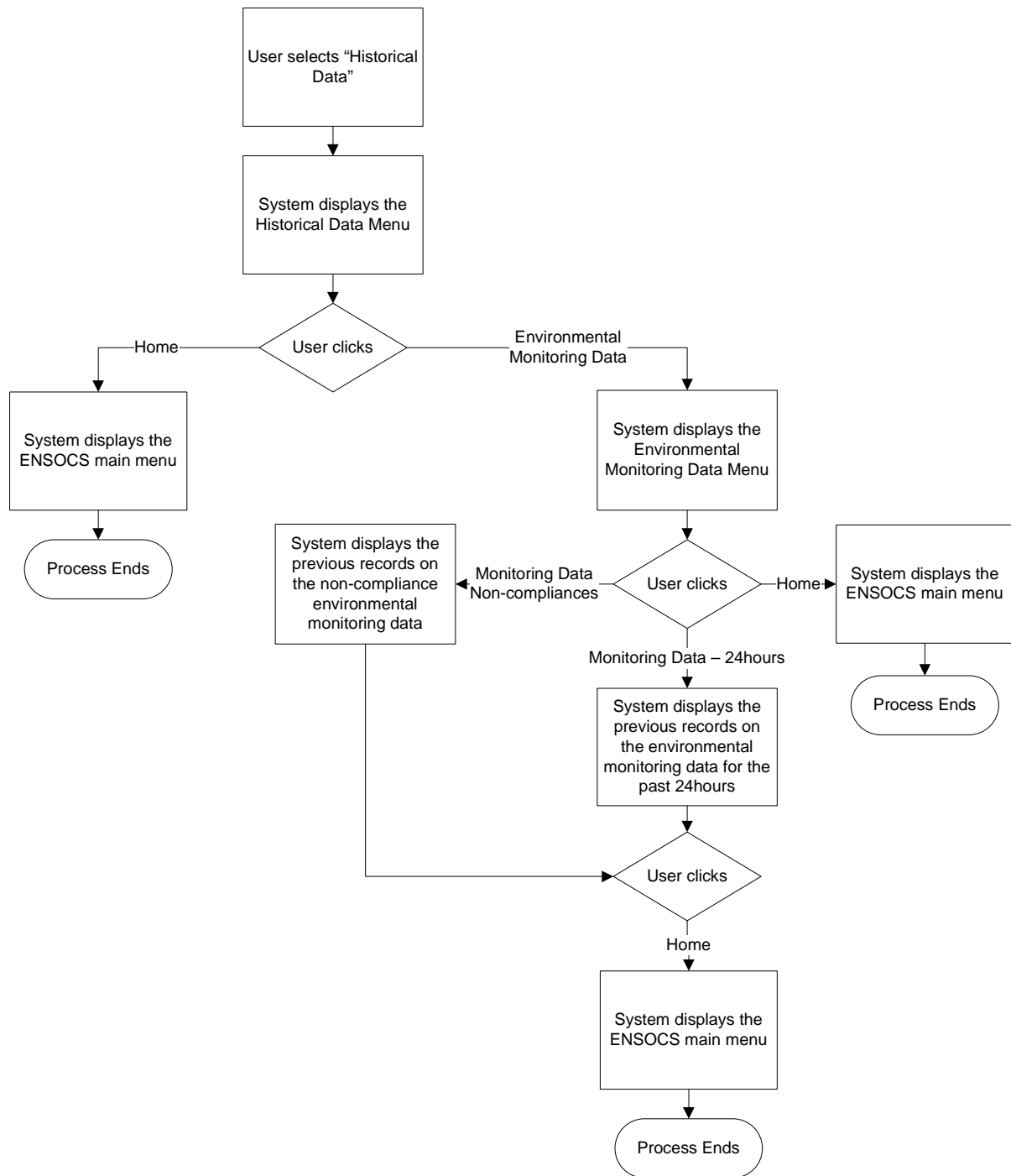
Alternative Flow of Events E1:

1. Process commence from Step 2 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Exceptional Flow of Events :

None

Use Case: Historical Environmental Monitoring Data of ENSOCS



Use Case Description:

This use case describes the process of a user to obtain the information pertaining to the previous records on environmental monitoring data sourced from the wireless monitoring sensor at the project site.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the reading of the PM₁₀ and Noise level during past 24hours.

Flow of Events :

1. User clicks on “Historical Data” icon.
2. System displays the webpage of Historical Data Menu which contains the features as follows:
 - a. Environmental Monitoring Data
 - b. Inspection Reports
3. User clicks on “Environmental Monitoring Data” icon.
4. System displays the webpage of Environmental Monitoring Data Menu which contains the features as follows:
 - a. Environmental Monitoring Data – 24 hours
 - b. Environmental Monitoring Data – Non-compliances
5. User clicks on “Environmental Monitoring Data – 24 hours” icon.
6. System displays the list of the PM₁₀ and Noise level for the past 24hours.
7. User clicks “Home” button.
8. System displays the ENSOCS main menu.

9. Use case ends.

Alternative Flow of Events E1:

1. Process commence from Step 2 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

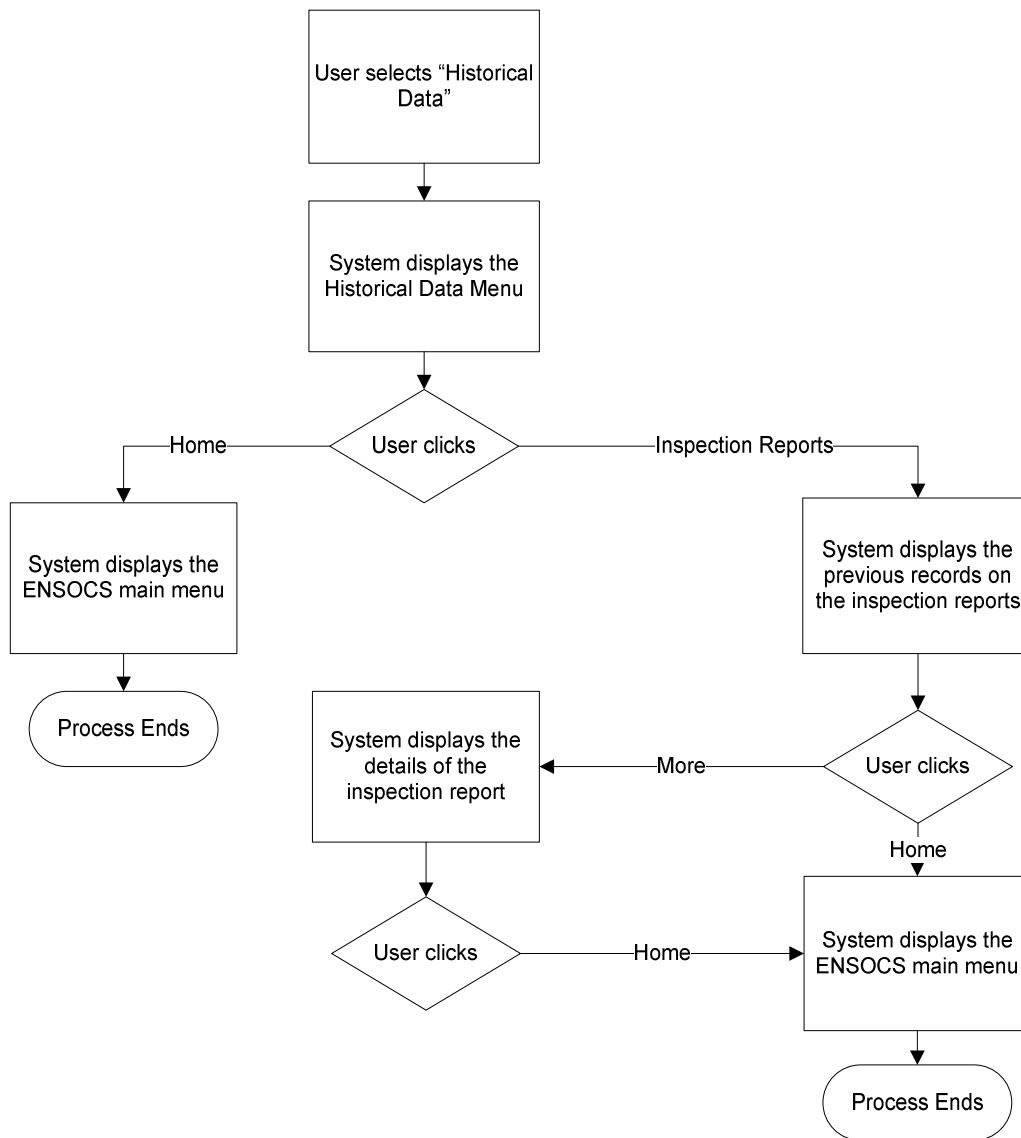
Alternative Flow of Events E2:

1. Process commence from Step 4 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Exceptional Flow of Events :

None

Use Case: Historical Inspection Reports of ENSOCS



Use Case Description:

This use case describes the process of a user to obtain the information pertaining to the previous records on the inspection reports produced by the environmental management team member for any surveillance activities carried out at the project site. User is allowed to view the previous the inspection reports on the system.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the list of the previous inspection reports.

Flow of Events :

1. User clicks on “Historical Data” icon.
2. System displays the webpage of Historical Data Menu which contains the features as follows:
 - a. Environmental Monitoring Data
 - b. Inspection Reports
3. User clicks on “Inspection Reports” icon.
4. System displays the webpage which contains the summary of the active inspection reports as well as the button to view the in-active inspection reports.
5. User reviews the list of inspection reports.
6. User clicks on the “more” link to reveal the detail information of the selected report.
7. User clicks on back button on the smartphone to go back to the previous webpage.
8. User clicks “Close” button.
9. System displays the list of the in-active inspection reports.

10. User reviews the list of inspection reports.
11. User clicks on the “more” link to reveal the detail information of the selected report.
12. User clicks “Home” button.
13. System displays the ENSOCS main menu.
14. Use case ends.

Alternative Flow of Events E1:

4. Process commence from Step 2 from above. User clicks “Home” button.
5. System displays the ENSOCS main menu.
6. Use case ends.

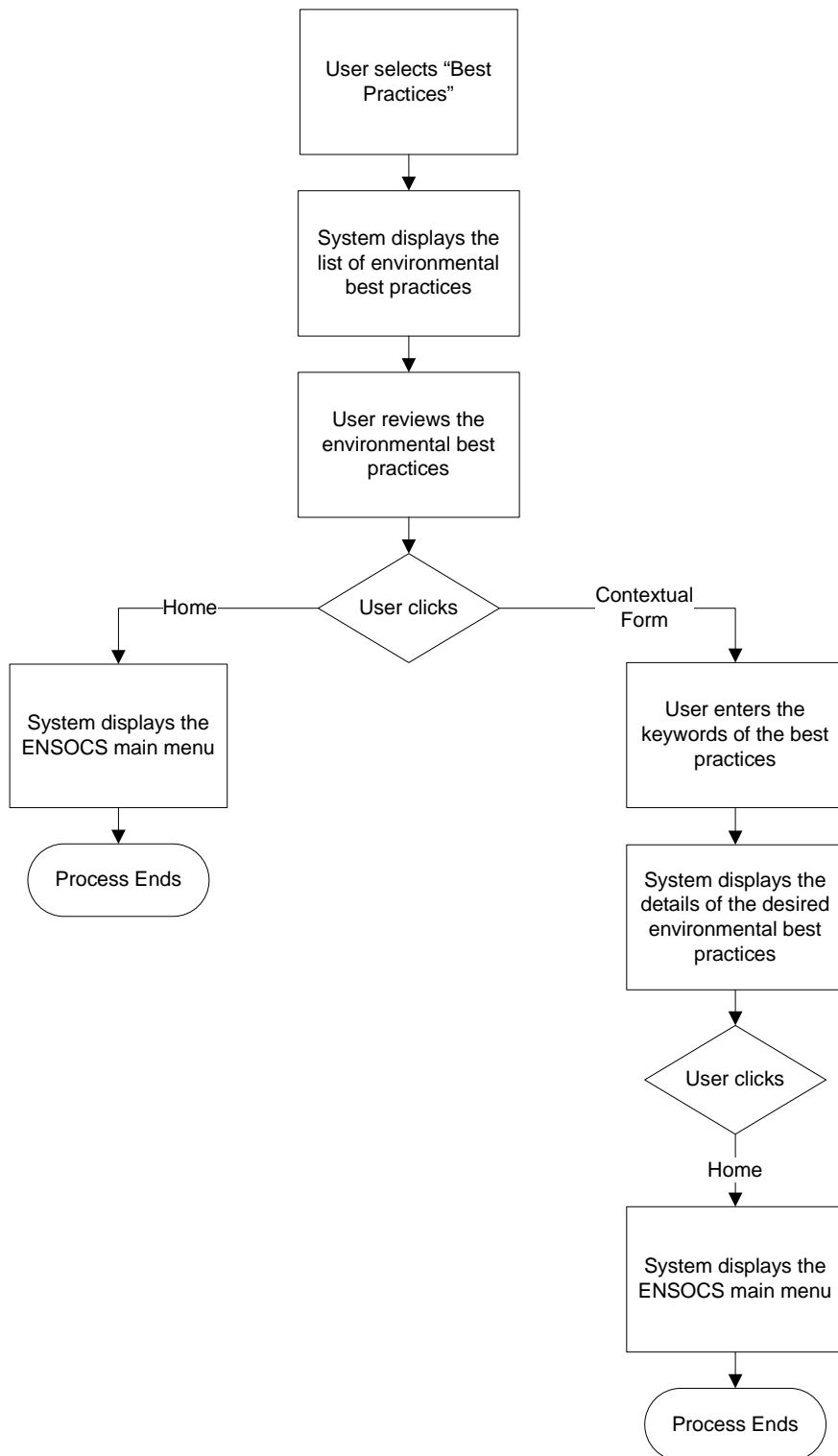
Alternative Flow of Events E2:

4. Process commence from Step 4 from above. User clicks “Home” button.
5. System displays the ENSOCS main menu.
6. Use case ends.

Exceptional Flow of Events :

None

Use Case: Environmental Best Management Practices



Use Case Description:

This use case describes the process of a user to obtain the information pertaining to the best management practices of the environmental management at the construction project. User is allowed to view the environmental best management practices or enters the keyword in the searchable form feature to retrieve the desired information.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the environmental best management practices or any specific practices based on the entered keyword by the user.

Flow of Events :

1. User clicks on “Best Practices” icon.
2. System displays the webpage which contains the list of the environmental best management practices.
3. User reviews the list of environmental best management practices and clicks on “more” (link) of any specific practices (e.g. Sediment Control) to reveal the details.
4. System displays the webpage which contains the detail explanation about the said best practices.
5. User reviews the best environmental management practices.
6. User clicks “Home” button.
7. System displays the ENSOCS main menu.
8. Use case ends.

Alternative Flow of Events E1:

1. Process commence from Step 2 from above. User enters the keyword in the searchable form feature.
2. System displays the specific practices based on the entered keyword by the user.
3. User reviews the best environmental management practices.
4. User clicks “Home” button.
5. System displays the ENSOCS main menu.
6. Use case ends.

Alternative Flow of Events E2:

1. Process commence from Step 2 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

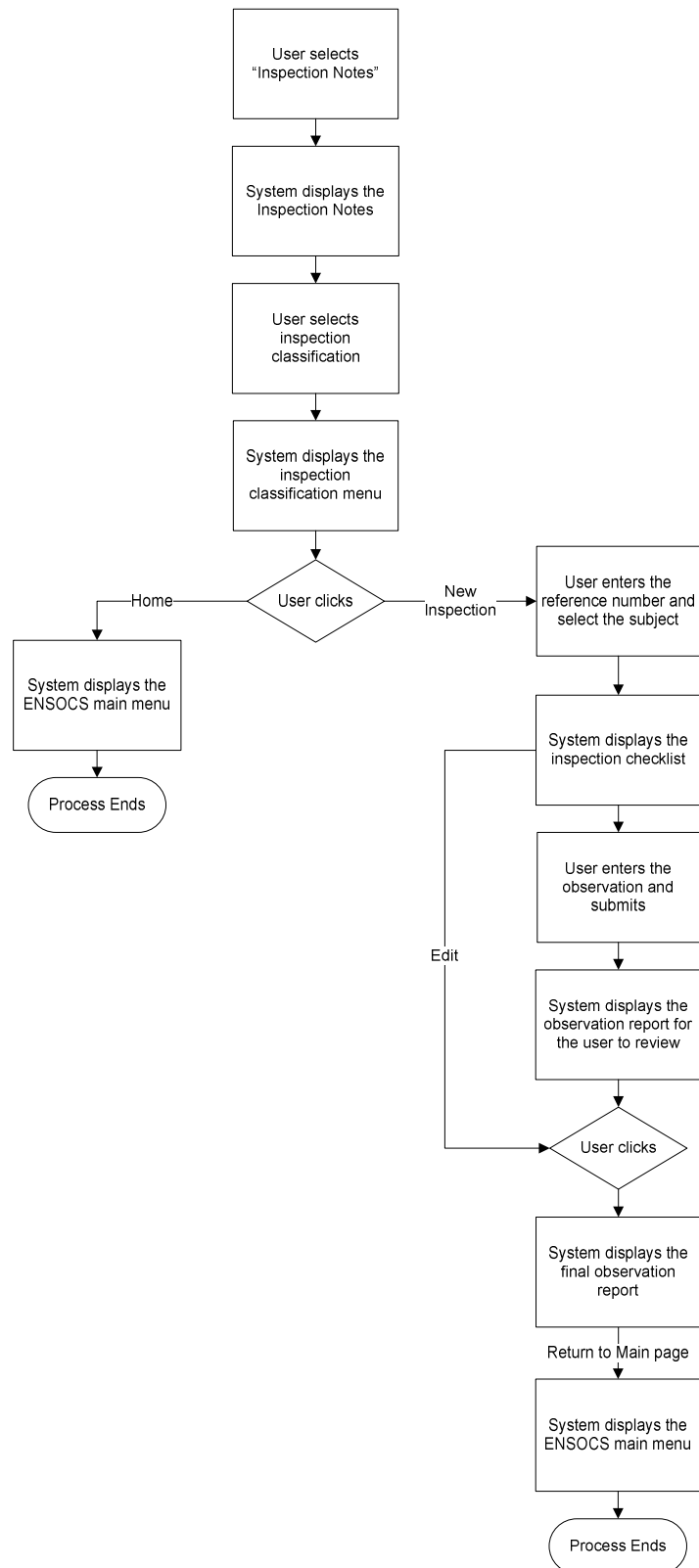
Alternative Flow of Events E3:

7. Process commence from Step 3 from above. User clicks “Home” button.
8. System displays the ENSOCS main menu.
9. Use case ends.

Exceptional Flow of Events :

None

Use Case: Preparation and submission of the inspection report.



Use Case Description:

This use case describes the process of a user to prepare and submit the inspection report to the database. User is allowed to enter the observation notes in the database and prepare the inspection report.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the inspection report based on the entered information by the user.

Flow of Events :

1. User clicks on “Inspection Notes” icon.
2. System displays the Inspection Notes Menu for the user to select the inspection classification as follows:
 - a. Transportation and road
 - b. Site housekeeping
 - c. Waste management
 - d. Land disturbance
3. User clicks on any classification icon.
4. System displays the inspection categories as follows:
 - a. New inspection
 - b. Follow-up inspection
 - c. Attach the photograph (update the previous report)
5. User selects the “New Inspection” icon.
6. System displays the webpage to let the user to enter the reference number and subject of inspection.
7. User enters the reference number and selects the appropriate subject, then clicks on “submit” button.
8. System displays the webpage which contains the site inspection checklist.
9. User enters the observation remarks and clicks on “submit” button.

10. System displays the webpage which contains the observation report for the user to review and do the correction if necessary.
11. User clicks on “proceed” button.
12. System displays the webpage which contains the final observation report.
13. User clicks “Home” button.
14. System displays the ENSOCS main menu.
15. Use case ends.

Alternative Flow of Events E1:

1. Process commence from Step 10 from above. User clicks on “edit” button.
2. System displays the webpage which contains the inspection’s checklist with previously entered information.
3. User enters the correction of the observation remarks and clicks on “submit” button.
4. System displays the webpage which contains the observation report for the user to review and do the correction if necessary.
5. User clicks on “proceed” button.
6. System displays the webpage which contains the final observation report.
7. User clicks “Home” button.
8. System displays the ENSOCS main menu.
9. Use case ends.

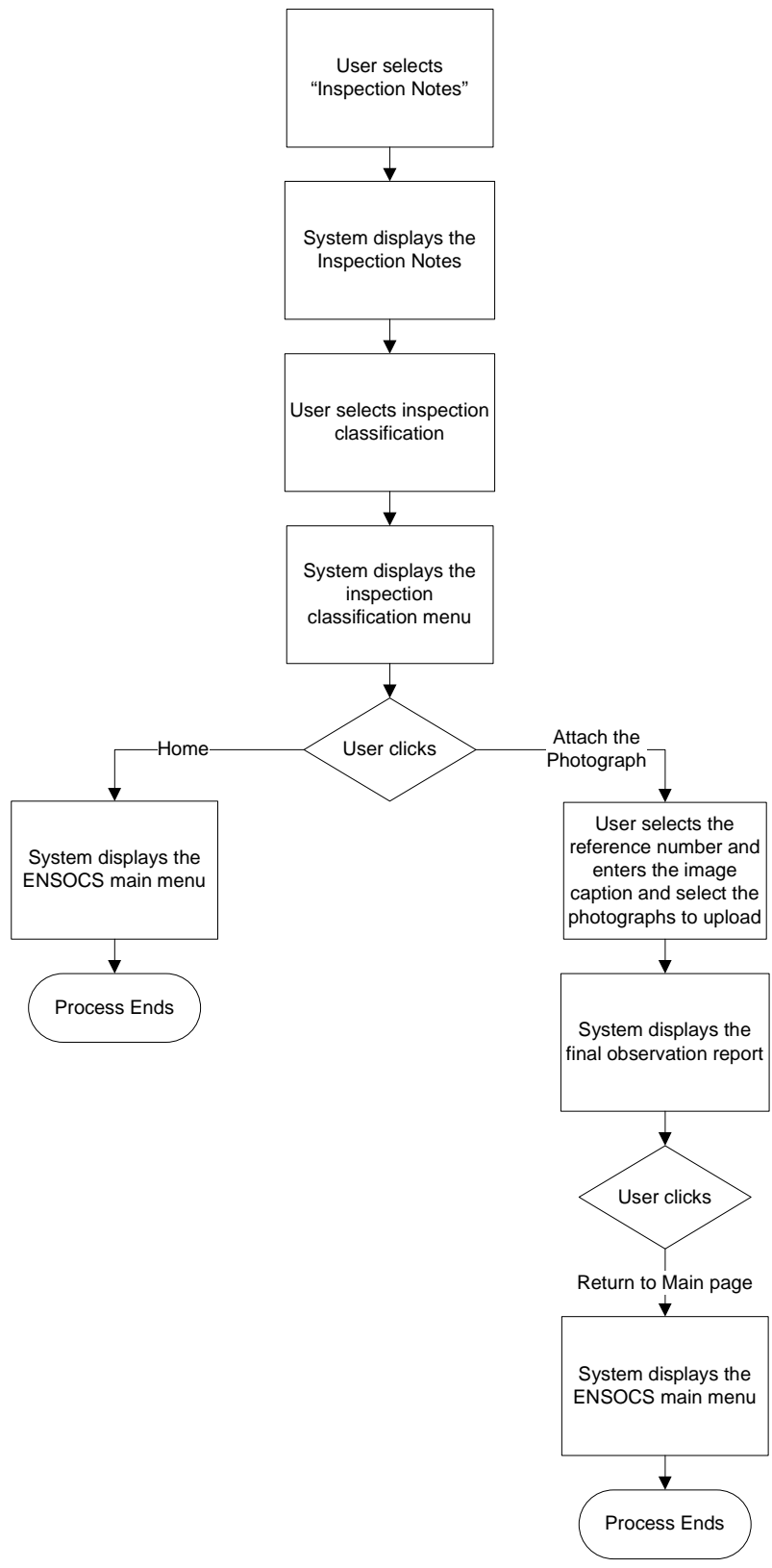
Alternative Flow of Events E2:

4. Process commence from Step 4 from above. User clicks “Home” button.
5. System displays the ENSOCS main menu.
6. Use case ends.

Exceptional Flow of Events :

None

Use Case: Attach a photograph to the inspection report.



Use Case Description:

This use case describes the process of a user to update the inspection report by uploading a photograph to the database. User is allowed to upload the photograph to the database and view the final inspection report.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System displays the inspection report based on the entered information by the user.

Flow of Events :

1. User clicks on “Inspection Notes” icon.
2. System displays the Inspection Notes Menu for the user to select the inspection classification as follows:
 - a. Transportation and road
 - b. Site housekeeping
 - c. Waste management
 - d. Land disturbance
3. User clicks on any classification icon.
4. System displays the inspection categories as follows:
 - a. New inspection
 - b. Follow-up inspection
 - c. Attach the photograph (update the previous report)
5. User selects the “Attach the photograph” icon.

6. System displays the webpage to let the user to select the reference number, enter the image caption and upload the photograph.
7. User selects the reference number, enter the image caption and upload the photograph.
8. System displays the webpage which contains the final observation report.
9. User clicks “Home” button.
10. System displays the ENSOCS main menu.
11. Use case ends.

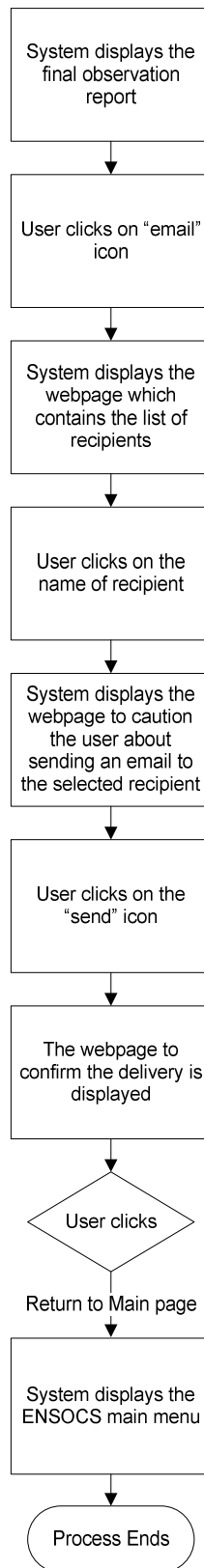
Alternative Flow of Events E1:

1. Process commence from Step 4 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Exceptional Flow of Events :

None

Use Case: Submission of the inspection report to the respective parties through an email.



Use Case Description:

This use case describes the process of a user to submit the final inspection report to the respective parties through an email. User is allowed to send an email which contains the final inspection report once the report was completed.

Actors :

1. Environmental Management Team Member

Pre-Condition :

1. User is login into the application.

Post-Condition :

1. System delivers the email which contains the inspection report based on the entered information by the user.

Flow of Events :

1. User clicks on “Inspection Notes” icon.
2. System displays the Inspection Notes Menu for the user to select the inspection classification as follows:
 - a. Transportation and road
 - b. Site housekeeping
 - c. Waste management
 - d. Land disturbance
3. User clicks on any classification icon.
4. System displays the inspection categories as follows:
 - a. New inspection
 - b. Follow-up inspection
 - c. Attach the photograph (update the previous report)
5. User selects the “New Inspection” icon.
6. System displays the webpage to let the user to enter the reference number and subject of inspection.
7. User enters the reference number and selects the appropriate subject, then clicks on “submit” button.

8. System displays the webpage which contains the site inspection checklist.
9. User enters the observation remarks and clicks on “submit” button.
10. System displays the webpage which contains the observation report for the user to review and do the correction if necessary.
11. User clicks on “proceed” button.
12. System displays the webpage which contains the final observation report with an option to send it through email.
13. User clicks on “email” icon.
14. System displays the webpage which contains the list of recipients.
15. User clicks on the name of recipient.
16. System displays the webpage to caution the user about sending an email to the selected recipient.
17. User clicks on the “Yes” icon.
18. The webpage to confirm the delivery is displayed.
19. User clicks “Home” button.
20. System displays the ENSOCS main menu.
21. Use case ends.

Alternative Flow of Events E1:

1. Process commence from Step 4 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Alternative Flow of Events E2:

1. Process commence from Step 12 from above. User clicks “Home” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Alternative Flow of Events E3:

1. Process commence from Step 16 from above. User clicks “No” button.
2. System displays the ENSOCS main menu.
3. Use case ends.

Exceptional Flow of Events:

None

APPENDIX 6

TEST CASE

Steps	Test Case ID:	<i>TC 0.1.1. Environmental Sensitive Receptors</i>		
	Description:	<i>Webpage to display the Environmental Sensitive Receptors surrounding of the project.</i>		
	Preconditions:	<i>The test user must obtain an access to the application and get into the main menu page.</i>		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	The test user executes the function by clicking on the “ Maps ” icon.	The webpage containing the icons of features is displayed.	Pass	
2	User clicks on the “ Environmental Sensitive Receptors ” icon.	The Google Map with demarcation of the project site’s boundary and tagging of Environmental Sensitive Receptors is displayed.	Pass	
3	User clicks on “ Home ” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Steps	Test Case ID:	<i>TC 0.1.2. Environmental Physical Surveillance</i>		
	Description:	<i>Webpage to display the site inspection checklist and enable the test user to generate the report.</i>		
	Preconditions:	<i>The test user must obtain an access to the application and get into the main menu page.</i>		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	The test user executes the function by clicking on the “Inspection Notes” icon.	The webpage containing the icons of environmental aspects is displayed.	Pass	
2	User clicks on the “Site Housekeeping” icon.	The webpage containing the inspection’s categories is displayed.	Pass	
3	User clicks on the “New Inspection” icon.	The webpage to let the user to enter the reference number and subject is displayed.	Pass	
4	User enters the reference number and selects the appropriate subject, then clicks on “submit” button.	The webpage containing the site inspection checklist is displayed.	Pass	
5	User enters the observation remarks and clicks on “submit” button.	The webpage containing the observation report is displayed for the user to review and do the correction if necessary.	Pass	
6	User clicks on “edit” button.	The webpage containing the inspection’s checklist with previously entered information is displayed.	Pass	

7	User amends the observation remarks and clicks on “ submit ” button.	The webpage containing the observation report is displayed for the user to review and do the correction if necessary.	Pass	
8	User clicks on “ proceed ” button.	The webpage containing the final observation report is displayed.	Pass	
9	User clicks on “ Home ” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Steps	Test Case ID:	<i>TC 0.1.3. Sending the report</i>		
	Description:	<i>The web system to send the observation report through an email to the relevant recipient.</i>		
	Preconditions:	<i>The test user must submit the data to the database, generate and finalise the report.</i>		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	User clicks on the “email” icon on the webpage containing the final observation report.	The webpage containing the list of recipients is displayed.	Pass	
2	User clicks on the name of recipient.	The webpage to caution the user about sending an email to the selected recipient is displayed.	Pass	
3	User clicks on the “send” icon.	The webpage to confirm the delivery is displayed.	Pass	
3	User clicks on “Home” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Steps	Test Case ID:	TC 0.1.4. Photo Uploads		
	Description:	System to display the webpage that would enable the user to update the inspection report by uploading the photograph.		
	Preconditions:	The test user must submit the data to the database, generate and finalise the report.		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	The test user executes the function by clicking on the “Inspection Notes” icon	The webpage containing the Inspection Notes Menu for the user to select the inspection classification is displayed.	Pass	
2	User clicks on “Site Housekeeping” icon.	The webpage containing the inspection categories is displayed.	Pass	
3	User selects the “Attach the photograph” icon.	The webpage to let the user to select the reference number, enter the image caption and upload the photograph is displayed.	Pass	
4	User selects the reference number, enter the image caption and upload the photograph.	The webpage contained the final observation report is displayed.	Pass	

5	User clicks on “Home” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Steps	Test Case ID:	<i>TC 0.1.5. Best Practices</i>		
	Description:	<i>Webpage to display the information on the best practices of environmental management at the construction sites.</i>		
	Preconditions:	<i>The test user must obtain an access to the application and get into the main menu page.</i>		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	The test user executes the function by clicking on the “Best Practices” icon.	The webpage containing the list of best practises of environmental management with smart searching features is displayed.	Pass	
2	User enters the keywords and clicks on “submit” button.	The webpage containing the information of the best practices as required is displayed.	Pass	
3	User clicks on “Home” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Steps	Test Case ID:	<i>TC 0.1.6. Historical Data- Inspection Reports</i>		
	Description:	<i>Webpage to display the all the previous inspection reports.</i>		
	Preconditions:	<i>The test user must obtain an access to the application and get into the main menu page.</i>		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	The test user executes the function by clicking on the “ Events ” icon.	The webpage containing the icons of features is displayed.	Pass	
2	User clicks on the “ Inspection Reports ” icon.	The webpage containing the list of previous inspection reports and their summary is displayed.	Pass	
3	User clicks on link “ more ” to reveal the details information.	The webpage containing the details of the report is displayed.	Pass	
4	User clicks on “ Home ” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

Steps	Test Case ID:	<i>TC 0.1.7. Realtime EQM</i>		
	Description:	<i>Webpage to display the realtime air and noise monitoring data gathered from the wireless sensor network on site.</i>		
	Preconditions:	<i>The test user must obtain an access to the application and get into the main menu page.</i>		
	Flow of Events	Post Condition	Result Pass/Failed	Comments
1	The test user executes the function by clicking on the “Live Boards” icon.	The webpage containing the icons of features is displayed.	Pass	
2	User clicks on the “Environmental Quality Monitoring” icon.	The webpage containing the reading of noise levels and PM10 is displayed.	Pass	
3	User clicks on “Home” button to go back to the main menu page.	The main menu page is displayed with all the main functions on the screen.	Pass	
End of Test Case				

APPENDIX 7

LIST OF PUBLICATIONS

HARUN, A. N. & BICHARD, E. & Nawi, M. (2015) Traditional vs Technological Based Surveillance on Construction Site: A Review. *Applied Mechanics and Materials*. 735. p. 247-252.

HARUN, A. N. & BICHARD, E. (2015) Supporting Environmental Surveillance on Construction Sites using Mobile Environmental Information System. *International Journal of Engineering Research and Technology*. 4. p.573-581.

HARUN, A. N. & BICHARD, E. (2015) Implementation Barriers of Mobile Environmental Information System for Environmental Surveillance on Construction Sites. *International Journal of Innovative Research in Science, Engineering and Technology*. 4(5). p. 3139-3146.