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Context-Aware Information Delivery For Mobile Construction Workers

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Abstract

The potential of mobile Information Technology (IT) applications to support the information needs of mobile construction workers has long been understood. However, existing mobile IT applications in the construction industry have underlined limitations, including their inability to respond to the changing user context, lack of semantic-awareness and poor integration with the desktop-based infrastructure. This research argues that awareness of the user context (such as user role, preferences, task-at-hand, location, etc.) can enhance mobile IT applications in the construction industry by providing a mechanism to deliver highly specific information to mobile workers by intelligent interpretation of their context. Against this background, the aim of this research was to investigate the applicability of context-aware information delivery (CAID) technologies in the construction industry.

The research methodology adopted consisted of various methods. A literature review on context-aware and enabling technologies was undertaken and a conceptual framework developed, which addressed the key issues of context-capture, context-inference and context-integration. To illustrate the application of CAID in realistic construction situations, five futuristic deployment scenarios were developed which were analysed with several industry and technology experts. From the analysis, a common set of user needs was drawn up. These needs were subsequently translated into the system design goals, which acted as a key input to the design and evaluation of a prototype system, which was implemented on a Pocket-PC platform.

The main achievements of this research include development of a CAID framework for mobile construction workers, demonstration of CAID concepts in realistic construction scenarios, analysis of the Construction industry needs for CAID and implementation and validation of the prototype to demonstrate the CAID concepts. The research concludes that CAID has the potential to significantly improve support for mobile construction workers and identifies the requirements for its effective deployment in the construction project delivery process. However, the industry needs to address various identified barriers to enable the realisation of the full potential of CAID.

**I dedicate this work to my parents
Their love, support and dedication has always been a source
of inspiration**

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List of Abbreviations

3G	Third Generation
ACE/FM	Architecture and Civil Engineering/Facilities Management
API	Application Programming Interface
CAID	Context-Aware Information Delivery
CC/PP	Composite Capability/
COBRA	Common Object Request Broker Architecture
EDI	Electronic Data Interchange
GPS	Global Positioning System
ICT	Information Communication Technologies
IP	Internet Protocol
IT	Information Technology
LAN	Local Area Networking
PAN	Personal Area Networking
RFID	Radio Frequency Identification
RMI	Remote Method Invocation
SUNA	Scenario-Based User Needs Analysis
UML	Unified Modelling Language
URI	Uniform Resource Indicators
WiFi	Wireless Fidelity (refers to IEEE 802.1x standards)
WLAN	Wireless Local Area Networking
WWW	World Wide Web
W3C	World Wide Web Consortium

Chapter 1: Introduction

1.1. Introduction

This chapter introduces the study by presenting the research background. The problem domain is defined and the key limitations in the existing state of the art of Mobile IT in the construction industry are highlighted. The final sections outline the research aims and objectives and present a guide to the thesis.

1.2. Research Background

Currently the construction industry is experiencing unprecedented change resulting from clients demanding better value-for-money, higher quality, shorter cycle times and access to the latest information, produced at any point in the project life cycle and supply chain (Anumba et al, 2003). This demand reflects the increasingly competitive pressure to implement techniques that can reduce project duration and cost, whilst improving productivity and performance. Growing trends of integration and decentralisation in the industry largely manifested through adopting design-build and partnering approaches, has added to these challenges. The need for innovative ways to face these challenges has long been recognised (Latham, 1994; Egan, 1998). Many challenges in today's construction processes arise from poor access to the right information at the right time for timely decision-making and from a general communication breakdown between the project participants (Kondratova et al, 2003). Thus, quality, quantity and timing of information is important, as it can either hinder or facilitate successful results (Garza et al, 1998). It is estimated by the construction

industry that potential time and cost saving through improved processes, by applying Information Communication Technologies (ICT), can constitute from 10% to 20% range (Rankin, 2002). ICT have advanced significantly in recent years and major advances such as the development of novel computational techniques and communication technologies (e.g. wireless and Internet technologies) are seen as primary tools to facilitate such a change and to overcome perceived shortcomings in current practice (Anumba, et.al 1997). In this regard, there has also been a movement towards the use of collaborative processes that leverage the Internet platform, thereby allowing participation of the project team, from the very early stages of the project. However, these Internet-based collaborative working solutions are tailored primarily towards the needs of desktop-based fixed network client. The collaboration needs of site-based staff and other mobile workers are not well addressed (Aziz et al, 2004; Bowden et al, 2002; Rebolj et al, 2002). As a result, the flow of electronic information comes to an abrupt halt when it reaches the construction site, only reaching selected personnel in the site office. Thus, many of the efficiency and knowledge-based benefits of ICT tools are lost. The extension of these ICT tools to support the information needs of mobile construction workers will be an essential factor in eliminating these problems (Bowden et al, 2002). Also, the information intensive nature of the construction project, the unstructured and dynamic nature of the construction site and the hazards and the difficulties presented by the on-site work necessitates the use of intelligent ways to support mobile construction workers (Anumba et al, 2003).

1.3. Research Context

The work presented in this research was done as part of an EPSRC funded WiSECON project. The project had two main aims:

- To investigate the applicability of Wireless-based technologies in the Construction industry.
- To explore the use of the 'Semantic Web' in the integration of distributed construction services.

The research programme followed the following objectives.

- Review developments and trends in the use of wireless devices, network infrastructure, standard practices in construction; along with identifying barriers, enablers, technical challenges and potential benefits of mobile and wireless technologies in construction.
- Review 'Semantic Web' technologies and concepts, with particular attention to the role of intelligent agents, ontology, common standards and possible applications within the construction business process;
- Identify areas of collaborative communications in construction that can be supported by wireless communication technologies that use agent based Semantic Web protocols as a process facilitator.
- Develop a system architecture and deployment models for a communications infrastructure based on the effective integration of these novel technologies with legacy systems within the construction industry;
- Develop prototype/experimental applications that demonstrate the use of wireless and Semantic Web-based applications to facilitate the construction process

The WiSECON project adopted a two pronged approach to investigate the applicability of Wireless and the Semantic Web technologies in the construction industry. The work presented in this thesis relates to the wireless dimension of the WiSECON project.

1.4. Mobile Computing in Construction – State of the Art

The need to address the aforementioned information needs of mobile construction workers have long been understood (Murray & Thorpe, 1996; Tenah, 1996; Garza & Howitt, 1998). As highlighted by Menzel et al (2004), discussions are no longer on whether or not to use mobile computer-supported solutions but, rather, on how they should be implanted and used. Parallel to this, there have been significant advances in mobile communication technologies in terms of improved wireless bandwidth, quality of service and cost. Also, a wide range of portable devices, such as PDAs, mobile phones and other wearable equipment are emerging, supporting real-time connectivity and improved processing power and battery life (Anumba et al, 2003). As a result, the opportunities for providing an intelligent support infrastructure to support mobile construction workers are increasing exponentially.

To exploit the potential of emerging mobile communication technologies, many recent research projects have focused on the application of these technologies in the construction industry. Some of these are discussed here. Garza and Howitt (1998) examined the use of wireless communications and computing on construction sites, giving particular consideration to the trade-off between the value of wireless information transmission against the cost of transmitting it. The COSMOS project

produced an integrated system for mobile operations support in the construction industry, focusing on construction sites lacking a permanent network infrastructure (Meissner et al, 2001). The SABARECO project demonstrated satellite-based communication between remote construction sites using standards such as TCP/IP and IFC/XML (Boehling, 2002). Liu et al (2001) focused on the optimisation of Internet use by low-end handheld mobile computing devices through remote pre-processing of jobs (Liu et al, 2001). Shiratuddin et al (2002) used handheld computer for 3D visualisation of design components and assemblies of construction projects. Rebolj et al (2001) conducted an experiment in which different aspects of mobile computing were tested on a construction site. While, in an another project Rebolj et al (2002) investigated mobile product models to structure the project information so as it could be effectively displayed on mobile devices. Saidi et al (2002) investigated the use of hand-held computers in the construction industry for different field activities including punch-listing, materials management, tracking, drawing access and quantity surveying and showed the time and cost saving potential. Yabuki et al (2002) developed an inspection support system using PDAs and RFID tags. RFID tags were attached to building components and served as a hook to retrieve relevant inspection data. Menzel et al (2002) investigated the possibility of context sensitive data management on mobile devices, adapting the amount of information delivered to the device based on the computing power and the size of the screen. A feasibility study for using wearable computers in construction (Fuller & Sattineni, 2002) showed that the relatively high cost of rugged industrial wearable computers prevents its wide spread usage on construction sites. Ward et al (2002) implemented a WLAN-based system for wireless data collection on the construction site. Kuladinithi et al (2004) demonstrated the potential of mobile ad-hoc communications within the construction

industry. In recent years, many researchers have also explored the potential of Global Positioning System (GPS) based location-tracking technologies for construction applications. Bacheldor (2002) used a mobile device with a GPS receiver for construction damage assessment. Morse et al (1998) demonstrated the potential of using hand-held computers connected to a GPS receiver to support fieldwork, while Giroux et al (2002) explored the possibility of location-referencing field applications including field data collection forms, control of environmental sampling during site inspection, and on-site training. The aforementioned research projects have demonstrated the potential of mobile communication technologies to support field work and to enable collaboration at several different levels.

However, the widespread application of mobile computing on the construction site still remains an untapped potential with many mobile workers effectively prevented to the mobile information flows that exist (Thorpe et al, 2005). Very often, mobile applications are designed to support specific high end objectives e.g. site record keeping and quality inspections (Cox et al, 2002), resource management and site audits (McCullough et al, 1993). The selective application of mobile communication technologies often results in a mixed handling of data, where a set of manual and semi-automated processes work together, resulting in a negative impact on the process workflows (Aziz et al, 2003). Many reasons have been cited for the lack of widespread adoption of mobile computing in construction (Bowden et al, 2002; Anumba et al, 2003) including:

- Perceived high initial equipment cost;
- Perceived lack of rugged devices;
- Perceived lack of computer literate workers;

- Perceived complexity of application deployment; and
- Lack of understanding of user requirements.

However, with the decreasing costs and fast pace of mobile-IT related technology growth, it has become possible to address many of the technology related shortcomings of mobile IT deployment in the construction industry.

1.5. Problem Domain

The state-of-the-art in mobile communications in the construction industry (as discussed in Section 1.4) have some underlined limitations, which are discussed below:

1.5.1. Existing Mobile IT Applications Lack Context-Awareness

From a methodological viewpoint, existing mobile communication deployments in the construction industry see support for mobile workers as a "simple" delivery of the information (such as project data, plans, technical drawings, audit-lists etc). Information delivery is mainly static and is not able to take into account the mobile worker changing context and the dynamic project conditions. Many research projects on the use of mobile devices for field data collection (e.g. Mrawira et al, 2002; Yabuki et al, 2002) relied on asynchronous methods of communication with no consideration of user-context, by downloading field data from mobile devices onto desktop computers and then transferring this information into an integrated project information repository. Even in those projects where the real time connectivity needs of mobile workers are addressed (e.g. Boehling, 2002; Meissner et al, 2001), the focus

is on delivering static information to users such as project plans and documents or access to project extranets. Similarly, most of the commercially available mobile applications for the construction industry target management staff (e.g. project management, quality assurance, health and safety etc.) and are designed primarily to deliver a pre-programmed functionality without any consideration of the user context. These applications are not aware of who the user is, what is profile/preferences are, what task (s)he is involved in and what existing project conditions are. As highlighted by Menzel et al (2002a), the construction industry is still lacking software systems designed to support specific on-site tasks, provide helpful guidance through these tasks, and support intelligent methods of human-computer interaction that take into account the context of on-site construction and supervision activities. This lacking often leads to a contrast between what an application can deliver and what data requirements of a worker are.

In contrast to the existing static information delivery approaches, the construction work, by its very nature, is dynamic. Due to the unpredictable nature of the construction projects, different activities are often difficult to anticipate and very often construction project plans, drawings, schedules, project plans, budgets etc have to be updated periodically. Also, the context of mobile workers operating on-site is constantly changing (such as location, task they are currently involved in, construction site situations and resulting hazards, etc) and so do, their information requirements. As highlighted by Hjelm (2000), in a mobile environment, users do not have the time to conduct extensive searches while on the move. Thus, mobile workers require that supporting systems understand who they are, where they are located and to deliver the

right information at the right time on as-needed basis. Such a capability is possible by a better understanding of the user-context (Aziz et al, 2005).

1.5.2. Existing Mobile IT Applications Lack Semantic Awareness

The existing construction processes require mobile workers to sift through huge amounts of project data to determine the relevant information. As a result, mobile workers' effectiveness to perform a particular task very often depends on their ability to remember the relevant information and documents and their relationships to one another. As tasks become more complex, the relationships between documents become even more complex. At the same time, busy project managers are often involved in several tasks and projects at the same time. This include real time progress monitoring of on-site works, remote expert support, on-site collection of qualitative and quantitative measurements, collaborative review of technical drawings, on-site supplier and subcontractor evaluation, on-site evaluation of equipment usage measurements, keeping track of the physical equipment position anytime and anywhere, answering audit checklists and filing audit reports during site audits (Meissner et al,2001). Very often the urgency of the situation does not allow enough time to search for the relevant information. Keeping track of all the tasks and related dependencies has become a formidable challenge. The application of technology to address such issues remains limited. Also, given the limitations of mobile devices (such as limited display size, limited battery power, storage capacity, low processing power, uncomfortable data input methods), undertaking such information search is even more difficult. All these point to the need for semantic awareness, in order to

help mobile workers (or computer programs) find the relevant information suited to the workers' context.

1.5.3. Poor Integration with the Desk-Top Based Infrastructure

From an architectural viewpoint, current mobile communication applications in the construction industry lack cohesion with the existing desktop based ICT infrastructure. Existing mobile applications are based on multiple technology platforms (e.g. Pocket PC, Tablet-PC, Palm etc) and rigid frameworks, that must be centrally managed and hand integrated at the source code level for integration with the existing desk-top based applications. This creates enormous problems in deployment, setting up and integration with the desktop infrastructure. Resulting complexity and heterogeneity results in inconsistent interface, redundancy and out-of-sync information. In recent years, the integration issue is being addressed through the use of proprietary or open standard APIs (Application Programming Interfaces). In this approach, each application needs a specialised API to communicate with another application (Fig 1-1). Figure 1-1 depicts a scenario illustrating the consequence of using an API based approach to system integration. Each of the APIs shown in Figure 1-1 are different, meaning that each application needs to have intimate knowledge of the connecting application. Also, many applications may in fact have more than one integration to another application, depending on the needs. As a new application is added to the system, a new API needs to be created.

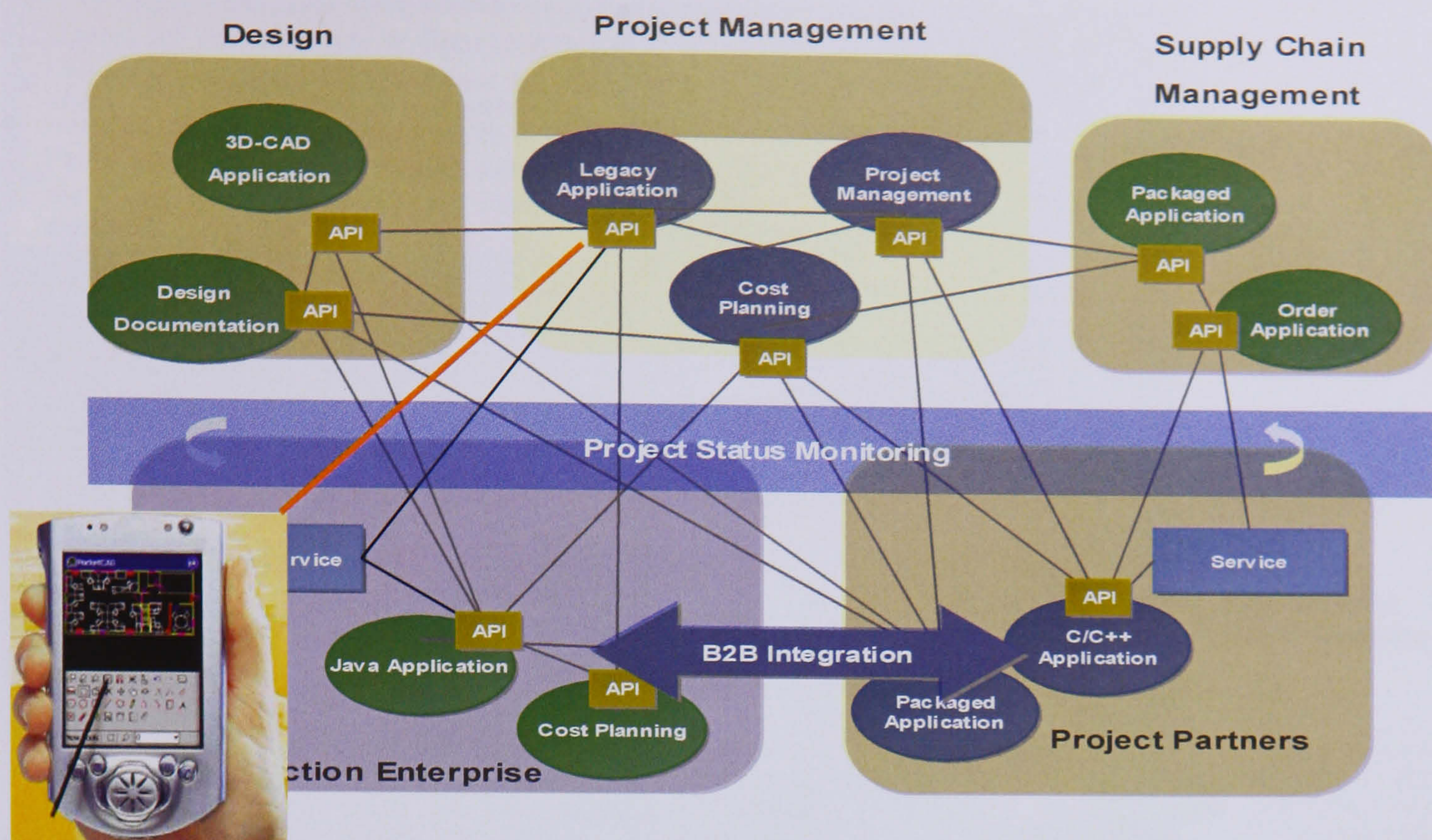


Figure 1-1: An API based integration approach resulting in inflexible systems

Some of the most obvious problems of using such an approach to system integration include:

- This approach towards integration is not scalable because of the node to node connections required (assuming that proprietary APIs are used).
- Such an integration approach may address the problem of local or project based integration, but is inadequate to ensure seamless information flow between different applications.
- Another major drawback of such a tightly coupled system is that system is fairly fragile. If one node down, the entire system can fail.

As a consequence, such an ad-hoc approach towards mobile application development and integration will create another island of automation (Figure 1-2).

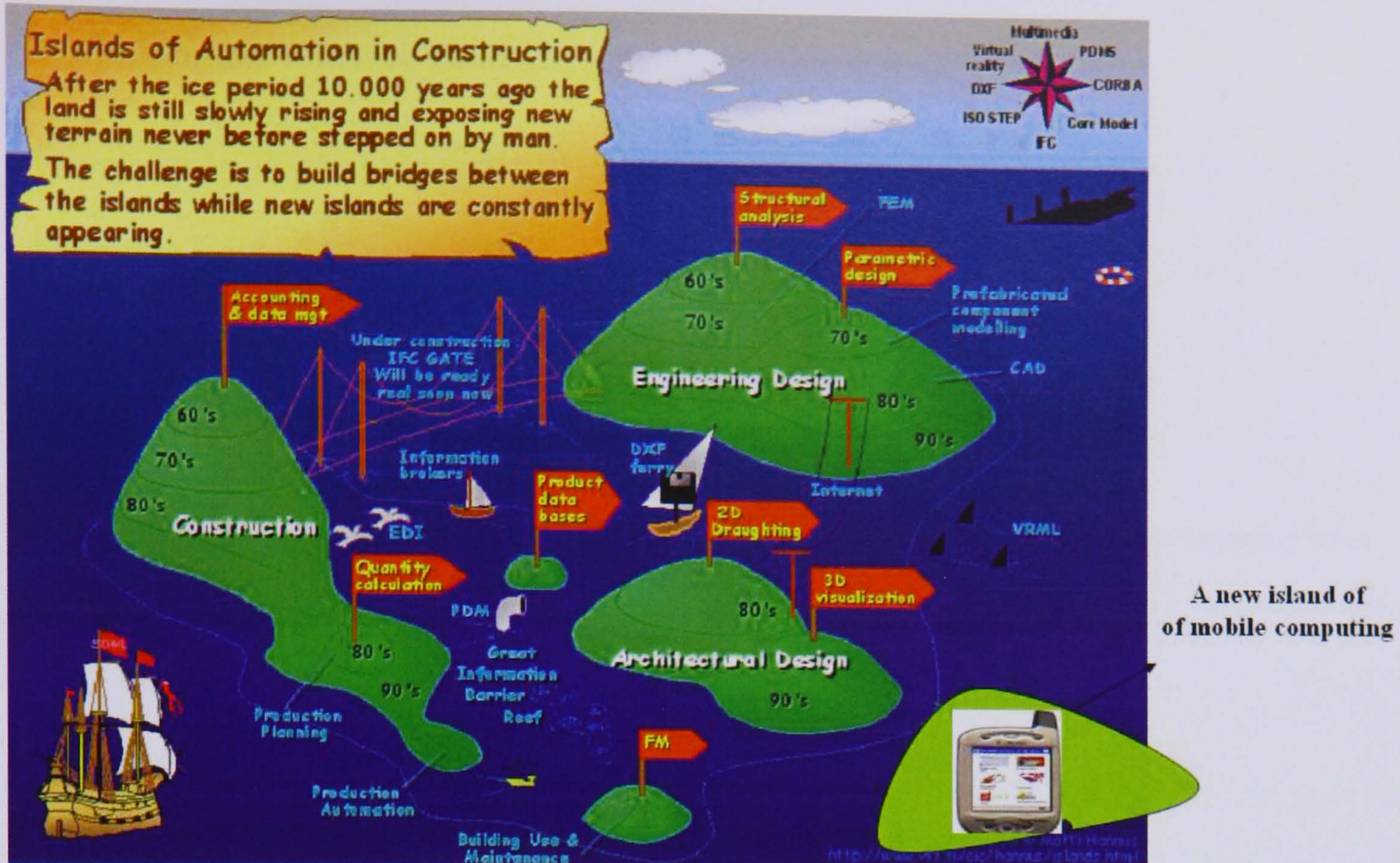


Figure 1-2: Creating a new island of Mobile Computing (adapted from Hannus, 1998)

1.5.4. Limited Understanding of Mobile Worker Requirements

Current deployment of wireless applications for the construction industry is confronted with a situation in which technology and services were designed without a detailed understanding of the contexts in which these systems will be used, and user requirements (Anumba et al, 2003). Some attempts have been made in addressing part of these problems but the approaches used have not been holistic. Much effort was focused on adapting off-the-shelf commercial products to the construction market. Additionally the choices available to enable mobile working has led many organisations to focus on managing the technology aspect of deployment (software, hardware, networking issues etc) rather than the actual tasks that the device will help the user to accomplish. As a result, on many occasions technology has failed to meet the information requirements of mobile construction workers (Anumba et al, 2003).

1.5.5. Limited Work to Integrate Emerging Technologies

From a technological point of view, there has been limited work to integrate emerging technologies (such as the Semantic Web, Web services, Agents, Context-Aware computing) within the construction work environment.

All the aforementioned factors affect the value proposition of mobile communications in the construction sector.

1.6. Possible Solutions

In order to discuss the possible solutions of problems described in Section 1.5, this section presents these in the form of assertions, which have been structured as a chain of reasoning, and have bearing on the research aims and objectives.

Assertion 1: Understanding of the mobile worker's context can effectively be used to improve construction communications

Section 1.5.1 discussed how existing Mobile IT applications primarily rely on static modes of information delivery, which often result in a mismatch between what an application can offer and the actual (data) requirements of mobile workers. It is argued here that the awareness of user context (such as user profile/role, preferences, task, location, existing project conditions etc) can enhance mobile computing applications in the construction industry by providing a mechanism to determine information relevant to a particular context. In recent years, the emergence of powerful wireless Web technologies, coupled with the availability of improved bandwidth, has enabled mobile workers to access in real time different corporate

back-end systems and multiple inter-enterprise data resources to enhance construction collaboration. Context-aware information delivery adds an additional layer on top of such real time wireless connectivity (Aziz et al, 2005) offering the following benefits:

- Delivery of relevant data based on the worker's context (such as profile, task-at-hand, location, etc). This way, it is possible to eliminate distractions for mobile workers, related to the volume and level of information;
- User interaction with the system can be reduced by using context as a filtering mechanism to deliver only context-relevant information to users. This has the potential to increase usability, by decreasing the level of interaction required between the mobile devices (which are constrained by limited interface size) and the end-users. As highlighted by Rebolj et al (2005), a more detailed understanding of the context can bring a higher level of abstraction to mobile devices and make them a better mediator to the virtual world.
- Awareness of mobile worker's context, through improved sensing and monitoring can also be used to improve security and health and safety practices on the construction site;
- Awareness of user-context is a new interaction paradigm in construction communications, with a potential to enable a wide range of new services such as profile based task allocation, location based content delivery etc.

All the aforementioned factors can enhance the uptake of mobile communications in the construction industry. Similar observations were previously made by Rebolj et al (2003), who stated that mobile computing implies the following facts:

- a) A mobile computer is bound to a specific person;

- b) The location of a mobile computer can become a significant piece of information;
- c) The mobile computer (and thus the mobile worker) is available anytime, anywhere; and
- d) The mobile worker has access to the system anytime, anywhere.

In the light of the aforementioned factors, Rebolj (2003) concluded that a communication system, adaptable to the project and the user needs is one of the possible solutions to improve existing information systems and to decrease the gap between research in information technology and the state of the practices of everyday work. In this respect, context-aware technologies can play a critical role by bridging the gap between the virtual world (as enabled by elements of ICT infrastructure) and the physical world of actual construction operations (Fig 1-3). In Figure 1-3, context-awareness is used as an umbrella term to describe technologies that can be used to bridge the gap between the physical world of construction operations and the virtual world of ICT infrastructure. Bridging this gap would make construction applications aware of the on-site activities. This knowledge can be used to deliver context-relevant information to mobile workers. At the same time, it is possible to use the knowledge of on-site activities to improve site-logistics, site-security and Health and Safety conditions on the site. Some of the technologies which can help to bridge the gap between the virtual and the real worlds (such as user profiling, ubiquitous computing, RFID and sensor networking) are discussed in more detail in Chapter 3.

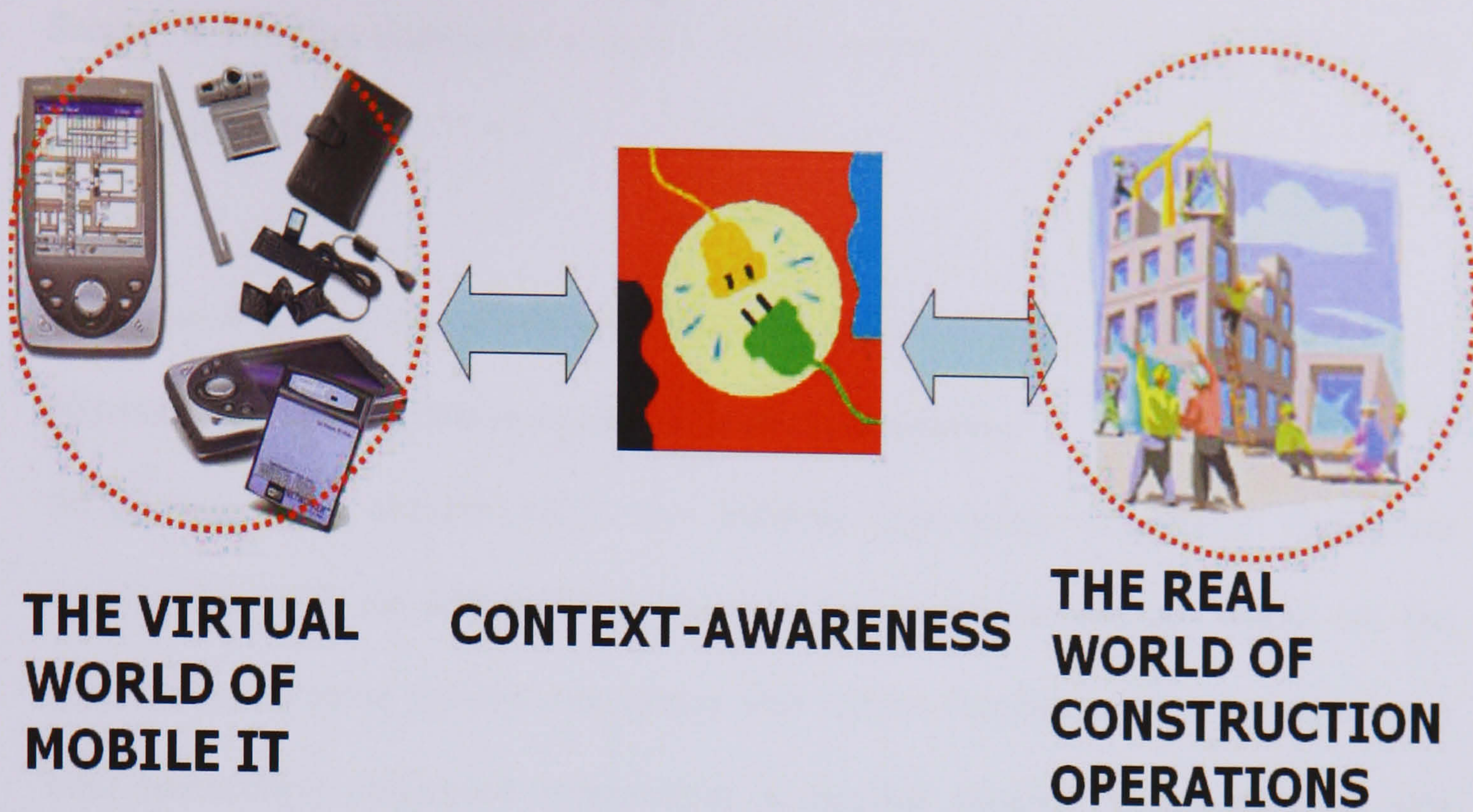


Figure 1-3: Bridging the gap between virtual and physical worlds through better context-awareness

Assertion 2: Semantic awareness is important to best utilise the captured contextual information

Semantic awareness is important for effective utilisation of captured contextual information in the following ways:

- To provide a standardised and semantically aware framework for shared definition of context, resources and their relationships. To enable semantics based reasoning about the captured context and resources;
- Better understanding of document and application semantics, which would allow better matching of the captured context with available resources.
- Application of Semantic Web technologies provide an application and platform-independent way to interpret context, thereby enabling both humans and software agents to infer new context knowledge and consequently take intelligent actions.

Section 4.3 further elaborates on how semantic awareness can contribute to effective context utilisation.

Assertion 3: Use of open-standards technologies is important to support resource discovery and integration in a context-aware environment

As discussed in Section 1.5.3, the existing approaches to mobile application development rely on API-based approaches for system integration, which has the potential to increase system complexity and reduce flexibility. In order to achieve inter-operability, structured information is needed instead of non-standard data formats (Rebolj et al, 2005). In recent years, many construction researchers (as described in Section 4.4) have recommended the use of open-standard approaches such as XML Web Services, to allow different applications and users to discover services and capabilities and to integrate dynamically. The relevance of such technologies for context-aware frameworks is discussed further in Section 4.4.

Assertion 4: A detailed understanding of end-user requirements is essential for optimal information delivery

Meyer et al (2003) described how research into future computing technologies is often far removed from the needs of the user and as a consequence “the nature of such future systems is often too obtrusive”. While there is a need to integrate emerging technologies in the construction work environment, it is also important understand the requirements of end-users in the construction industry, so that the technology is rightly aligned to the needs of end-users. Also, the construction industry is characterised by a very high churn, where construction workforce is always on the move. For this reason, mobile communication devices need to be developed that are

very user-friendly to operate. Techniques such as dynamic user profiling, voice input and output can further make the system user friendly. Features such as context-sensitive selection of interesting information, suppression of irrelevant data and superfluous communications can also enhance the usability of mobile applications.

Assertion 4: There is a need to integrate emerging technologies in the mobile construction work environment

With the fast pace of technology growth in recent years, technologies are emerging which can be used to enhance support for mobile construction workers. Many of these technologies are complementary. It is important to explore how these technologies can effectively be integrated in the construction work environment in order to improve construction processes.

1.7. Aim and Objectives of Research

The previous section argued that the awareness of the user context (such as user profile/role, preferences, task, location, existing project conditions etc) can enhance mobile computing applications in the construction industry by providing a mechanism to deliver highly specific information and services to mobile workers by intelligent interpretation of their context. Against this background, the aim of this research is to study the potential use of context-aware information delivery technologies within the construction sector and then gauge its readiness for implementing such technologies. In order to achieve this aim the specific objectives of the research project are:

1. To review developments and trends in the use of context-aware computing and enabling technologies (such as the Semantic Web, Web Services, (multi) agent and wireless communication technologies, etc.);

2. To develop a conceptual framework and deployment scenarios of context-aware information delivery for mobile construction workers;
3. To develop an understanding of the construction industry's requirements for context-aware information and services delivery;
4. To implement a prototype application that demonstrates various aspects of context-aware information delivery in realistic construction situations; and
5. To evaluate the prototype with potential end-users and industry experts.

1.8. Research Procedure

The research procedure included literature review on Context-Aware technologies, development of a conceptual framework for context-aware information delivery, development of futuristic deployment scenarios in the construction industry context, validation of these scenarios with the construction industry and technology experts, identification of user needs, development of the prototype system based on the user needs, evaluation of the prototype system with industry experts, and future road-mapping to identify issues and gaps that need to be filled. Section 2.7 further elaborates on the research method adopted in this research.

1.9. Research Scope

Context-aware information delivery is a multi-disciplinary product of many different technologies. A wider range of technologies can be used to capture different context parameters from the construction site (such as Sensors, RFID, wireless networks, etc). At the same time, it is possible to capture a wide range of context parameters. However, in this work five context parameters are addressed including:

- Current location of a worker, which is captured via a wireless local area network-based positioning system;
- User device type, which is captured via a Microsoft.NET framework application;
- User profile, which is captured via association with mobile device's unique IP address;
- User's activity via integration with MS Pocket Outlook;
- Time via computer clock.

Also, awareness of user context can be used for a variety of applications in various AEC/FM applications. However, this research focuses on serving the information needs of on-site personnel. In terms of the standard 7-layered ISO Model for Communication (OSI, 1994) (Fig 1-4), this research effort focuses on the application (related to construction information delivery) and presentation (related to presenting information to different mobile devices) layer. Technical issues related to other communication layers (i.e. physical, data-link, network, transport and session layers) are considered beyond the scope of this work.

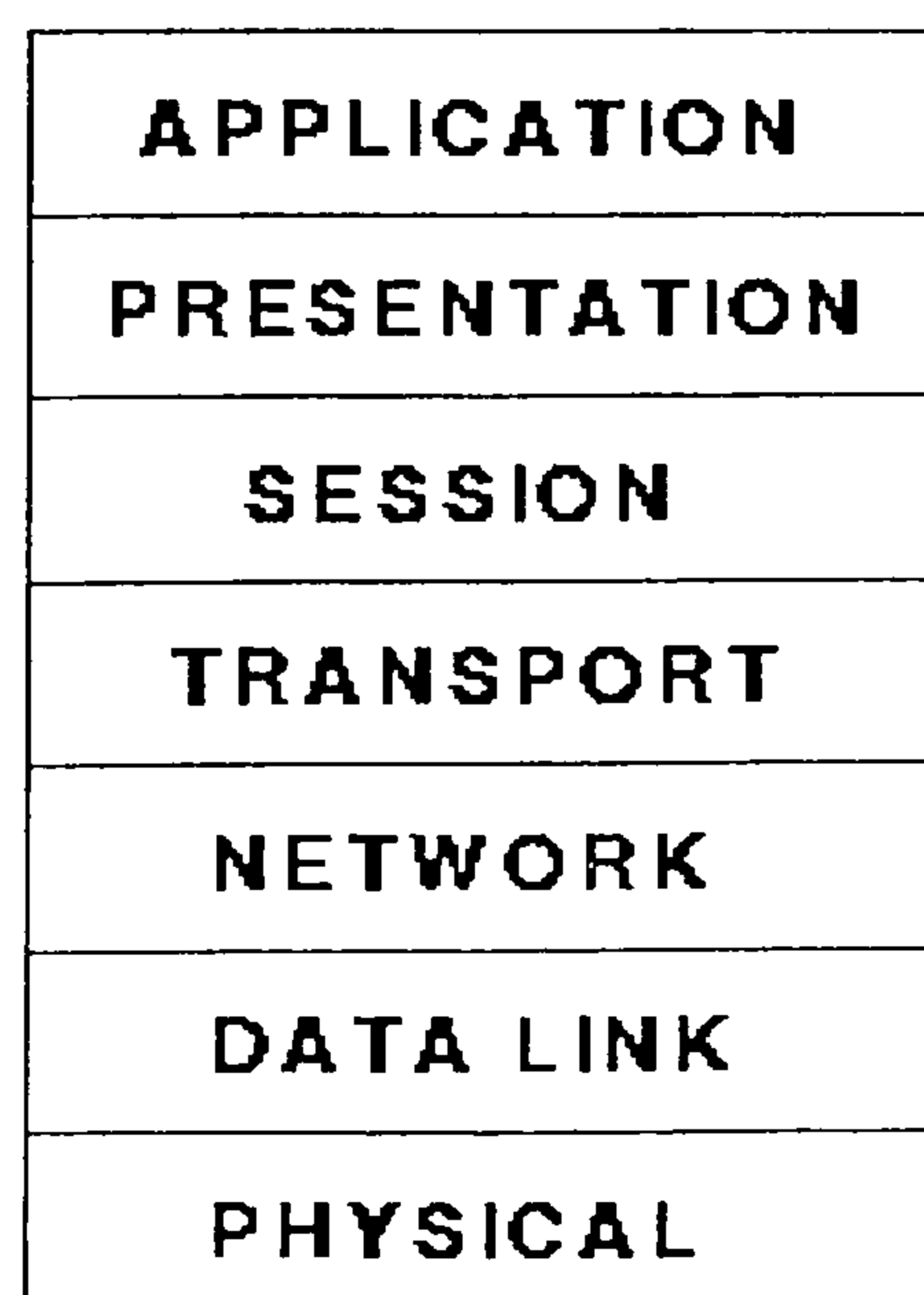


Figure 1-4: 7 Layered ISO Model for Communication (OSI, 1994)

This research addresses the practical need of ensuring that context-awareness is an integral component of Mobile IT infrastructure being used by the construction firms. As a result, this research has a rather broad focus as it addresses a wide range of issues (such as enabling technologies, the industry's needs etc) related to this theme.

1.10. Justification for the Research

As discussed in Section 1.5, existing mobile IT applications in the construction industry are constrained by their reliance on static methods of information delivery and lack of semantic awareness, which often result in a mismatch between the static information and the dynamic project conditions. This research focuses on a new interaction paradigm i.e. context-aware information delivery, which promises to match information delivery to changing information requirements of the mobile workers. Awareness of user context (such as role, profile, location, task, etc) can be used to enhance construction communications. The potential of improved productivity in the construction industry via improved communication is tremendous. At the same time, awareness of the user-context can also be used to improve site-logistics, site-safety and security.

This research takes a holistic view of context-aware information delivery, focusing not only on those technologies that can be used to capture user-context, but also addressing those that would help to reason about the context and take subsequent intelligent actions, based on the interpreted context. Such a holistic approach is important to address the industry's needs for an intelligent communications platform for mobile workers. Also, it is important to understand the construction industry

requirements for future context-aware information delivery technologies. The approach adopted involves participation of the industry experts in both the system design and the evaluation phase of this research. Futuristic application scenarios and a prototype application are developed, which demonstrates the application of context-aware information delivery technologies in realistic construction scenarios. This way it is ensured that the industry perspective is taken into account. Thus, findings from this research will contribute significantly to mobile IT research in the construction industry.

1.11. Thesis Structure

This thesis comprises nine chapters. Figure 1-5 illustrates the topics covered in each chapter. The content of each chapter is described below:

Chapter 1: Introduction

This chapter provides the general background to the research by describing the state of the art in mobile IT applications in the construction industry. The key limitations of the existing approaches are highlighted and some possible solutions are discussed. The final section outlines the research aims and objectives, and presents a guide to the thesis.

Chapter 2: Research Methodology

Chapter 2 provides an introduction to general research methodologies, and presents and justifies the methodologies adopted for various stages of this research. Various

approaches in Information Systems (IS) and Construction IT research are reviewed and research methods adopted in different phases of this research explained.

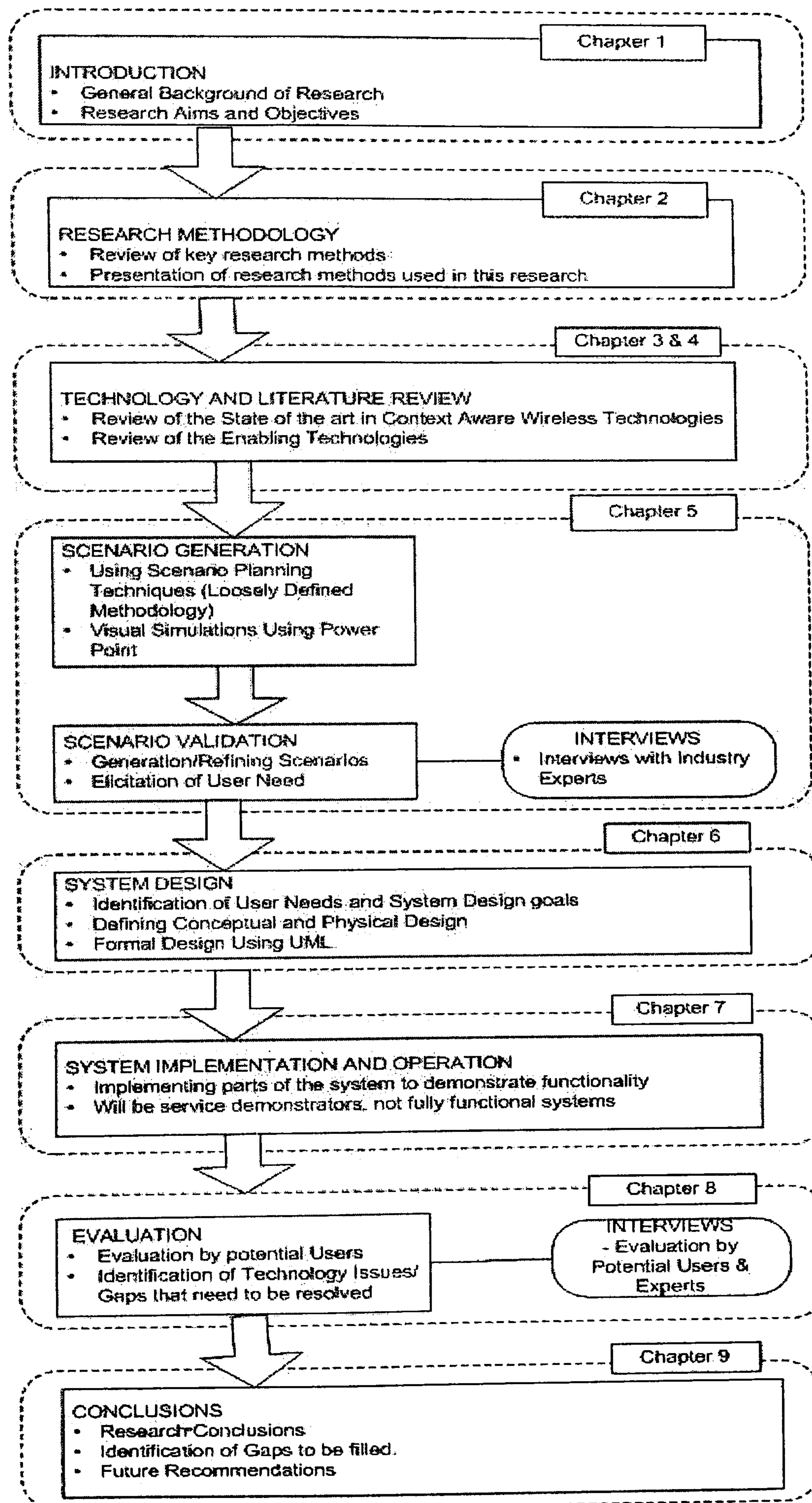


Figure 1-5: Thesis Structure

Chapter 3: Context-Aware Information Delivery

Chapter 3 presents the concept of context-aware information delivery and reviews related work in this area. It explains in detail the technologies related to context-aware computing such as location-based services, user profiling, ubiquitous computing and wireless sensor networking. Various context-aware information delivery frameworks are reviewed and the WiSeCon framework is presented, which aims to create a pervasive, user-centred mobile work environment, with an ability to provide highly specific data and services to mobile construction workers on as-needed basis.

Chapter 4: Enabling Technologies for Context-Aware Information Delivery

Chapter 4 reviews the enabling technologies for context-aware information delivery including Wireless Communications, the Semantic Web, Web Services and Agent-based Technologies. It also elaborates on how by exploiting the convergence and synergy between different enabling technologies, it has become possible to deliver intelligent wireless support to mobile construction workers.

Chapter 5: Scenario Generation and Validation

This chapter presents future scenarios illustrating the use of context-aware technologies in realistic construction situations. These scenarios were validated by bringing together the perspective of experts from different backgrounds. The key objective of the analysis was to pose the question of next generation context-aware mobile applications in the construction industry and to identify the industry's needs and application areas with the maximum potential.

Chapter 6: System Design

Chapter 6 describes the design and architecture of the prototype system. The end-user needs identified during the scenario-validation process (as documented in Chapter 5) were translated into system design goals using SUNA (Helvert, 2003) method. The system architecture is subsequently based on these design goals. Conceptual modelling is depicted in UML with a use-case driven approach, to illustrate the functional requirements of the system.

Chapter 7: System Implementation and Operation

Chapter 7 presents the implementation of the prototype system. The prototype was implemented on a Pocket-PC platform and demonstrated a working model of a context-aware delivery system for on-site construction operations.

Chapter 8: System Evaluation

Chapter 8 describes the evaluation objectives, the evaluation method used and an analysis of the evaluation results.

Chapter 9: Conclusions

Chapter 9 presents research conclusions. It discusses the research contributions made by this research, and make recommendations for practical applications and future research.

Chapter 2: Research Methodology

2.1. Introduction

This chapter starts by providing an introduction to general research methodologies, and presents and justifies the methodologies adopted for various stages of this research. It then reviews different approaches in Information Systems (IS) and Construction IT research. The research method adopted in this research is primarily based on the use of scenario-planning techniques for studying end-user needs and system design. The contents of Chapter 2 are illustrated in Figure 2-1 and are explained in the following sections.

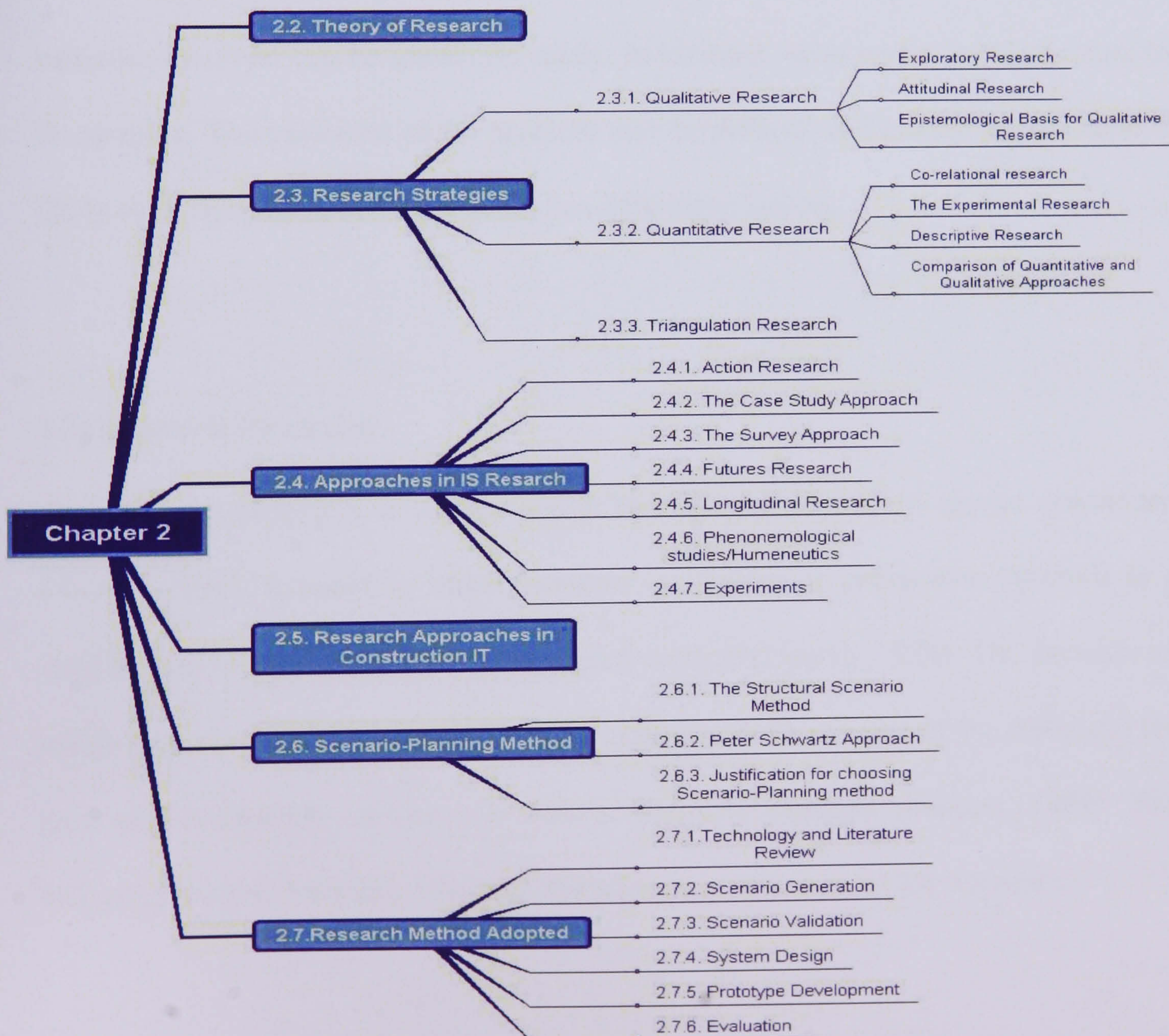


Figure 2-1: Chapter 2 Contents

2.2. Theory of Research

Research is defined as an art aided by skills of inquiry, experimental design, data collection, measurement and analysis, by interpretation and by presentation (Greenfield, 1996). A research method is a strategy of inquiry which moves from the underlying philosophical assumptions, to research design and data collection (Myers, 1999). There are two different types of research namely pure and applied research. Pure research is undertaken to develop knowledge and to contribute to the body of theory which exists. Applied research seeks to address issues of applications, to help solve a practical problem (Fellows & Liu, 2003). Typically, research involves solving either a close-ended or an open-ended problem. Close-ended problems are simple problems each with a correct solution. The existence of the problem, its nature and the variables involved can be identified easily. In contrast, open-ended problems tend to be complex. The existence of the problem may be difficult to identify, the situation is likely to be dynamic and the variables are difficult to isolate.

2.3. Research Strategies

The research strategy is a way in which the research objectives can be questioned (Naoum, 1998). It could be based on either qualitative or quantitative methods or a combination of both, called the triangulation method (Denzin, 1978). The decision on which type of research strategy to follow, depends on the purpose of the study and the type and availability of the information which is required (Naoum, 1998). The following section describes the main characteristics of key research strategies.

2.3.1. Qualitative Research

Qualitative research seeks to understand how people see and interact with the world (Fellows & Liu, 1997). It is 'subjective' in nature and consists of "detailed descriptions of situations, events, people, interactions and observed behaviour" (Patton, 1992). In qualitative research, an exploration of the subject is undertaken without prior formulations - the object is to gain understanding and collect information and data such that theories will emerge. Thus, qualitative research is a precursor to quantitative research (Fellows & Liu, 1997). Naturalistic observation, case studies, ethnography, and narrative reports are tools used for qualitative research (Linn and Erickson, 1990). Analysis of qualitative data is more difficult than quantitative data, requiring a lot of filtering, sorting and other manipulations to prepare them for analytical techniques (Fellows & Liu, 1997).

Guba et al (1994) suggest four epistemological classifications for qualitative research, which are described below. An epistemological classification concerns the question of what is (or should be) regarded as acceptable knowledge in a discipline (Bryman et al, 2003).

- **Positivist Research:** Positivist research advocates the application of the methods of the natural sciences. Orlikowski & Baroudi (1991) classified Information Systems research as positivist if there is evidence of formal propositions, quantifiable measures of variables, hypothesis testing and the drawing of inferences about a phenomenon from the sample to a stated population.
- **Post-positivism:** This is a recent development of positivist ideas where it is recognised that complete objectivity (truth) is unachievable. Results are

considered true if all procedures to establish validity have been exhausted. Findings are viewed as not being absolute (Guba and Lincoln, 1994).

- **Interpretive (or interpretative) Research:** Interpretive research indicates that reality is constructed by how human beings interpret and make sense of reality (Fellow & Liu, 2003). Researchers approach participants not as individuals who exist in a vacuum, but within the whole context of their lives (Holloway, 1997).
- **Critical Theory:** Critical theory takes the view that human beings are able to critically assess and change society and become emancipated. Objective reality is criticised (Gittins, 2005).

The information gathered in qualitative research can be classified under two categories, namely exploratory and attitudinal research (Naoum, 1998).

2.3.1.1. Exploratory Research

Exploratory research is conducted for three interrelated purposes: diagnosing a situation, screening alternatives, and discovering new ideas (Zikmund, 1997). A central feature of this type of research is the use of a hypothesis. Either a hypothesis is set up and then tested via research (data collection, analysis, interpretation of results) or a complex array of variables is identified and hypotheses are produced to be tested by further research (Fellows & Liu, 1997).

2.3.1.2. Attitudinal Research

Attitudinal research is used to subjectively evaluate the opinion, view, or the perception of a person, towards a particular object. The term 'object' refers to an 'attribute' a 'variable', a 'factor' or a 'question' (Naoum, 1998).

Different types of qualitative research such as the case-study and action research are discussed in more detail in Section 2.4.

2.3.2. Quantitative Research

The quantitative research method is about gathering factual data and studying relationships between facts in order to find out how these relationships agree with theories of previous research findings. These approaches adopt a 'scientific method' in which the initial study of theory and literature yields precise aims and objectives with hypotheses to be tested (Fellows & Liu, 2003). Co-relational, descriptive and quasi-experimental/experimental research are some of the tools used for quantitative research (Linn and Erickson, 1990): These are explained below.

2.3.2.1. Co-relational Research

The co-relation is a measure of the strength of the relationship between two variables (Bryman & Bell, 2003). This type of research examines the nature of the relationship between variables such as simple (statistical methods that yield a single number), predictive (improve capacity to anticipate events), and modelling (path analysis, graphical maps, etc.) (Locke et al, 1998).

2.3.2.2. Experimental Research

The experimental research method is best suited to known problems where the variables involved are identified or hypothesised with some confidence (Fellows & Liu, 1997). There are two approaches to the experimental research: laboratory experiments and field experiments. The laboratory experiment takes place in a laboratory or in a contrived setting, whereas field experiments occur in a real-life settings, such as in classrooms and organisations (Bryman & Bell, 2003). The key advantage of experimental research is the ability of the researcher to isolate and control a small number of variables that may be then studied in more depth. The major weakness is the limited extent to which the identified relationships exist in the real world. Also, in the experimental research, there are difficulties in finding organisations or groups of people prepared to be experimented upon.

2.3.2.3. Descriptive Research

The descriptive research method systematically identifies and records a phenomenon, process or a system. Such identification and recording is usually done from a particular perspective and often for a specified purpose (Fellows & Liu, 1997). Commonly, such research is carried out to enable the subject matter to be categorised.

2.3.3. Comparison of Qualitative and Quantitative Methods

The distinction between qualitative and quantitative research is not very clearly defined, because it is almost simultaneously regarded by some writers as a

fundamental contrast and by others as no longer useful or even simply as 'false' (Layder, 1993). For instance, it is possible to take a quantitative approach to many issues that are qualitative in nature (Moore, 2000). Similarly, several qualitative decisions should be made when using quantitative methods (e.g. the questions to pose, the design to implement, the measures to use, the analytical procedures to employ, and the interpretations to stress) (Linn and Erickson, 1990). Table 2-1 presents a summary of the key features of quantitative and qualitative research. The key difference between the two approaches is that the quantitative research focus on quantifying data, while the qualitative methods focus on gaining an understanding of underlying attitudes and measurements.

Table 2-1: Comparison of quantitative and qualitative research (Adapted from Naoum, 1998; Bryman & Bell, 2003; Al-Ghassani, 2003)

Criteria	Quantitative Research	Qualitative Research
Role	Fact-finding based on evidence or records	Attitude measurement based on opinions, views and perceptions measurement
Nature	Soft-science	Hard-science
Sample	Usually large in number, representative of the population and based on randomly selected respondents	Usually small in number, non-representative of population and respondents selected to fulfil a given requirement
Data Collection	Structured Questionnaires	Unstructured or Semi-Structured interviews
Data Analysis	Statistical	Non-statistical
Role of theory in relation to research	Deductive; testing of theory	Inductive; generation of theory
Relationship between researcher and subject	Distant	Close
Relationship between theory/concepts and research	Testing/confirmation	Emergent/ development
Nature of data	Hard and reliable	Rich and deep
Theory Development	Develops theory	Tests theory
Outcome	Findings are conclusive, they can be generalised and are used to recommend a final course of action	Findings are not conclusive, they can not be generalised and are usually exploratory and/or investigative

2.3.4. Triangulation

Triangulation involves the use of a mixture of quantitative and qualitative research tools. Although some scholars insist that either a quantitative or qualitative research method should be used, a combination has proven to be effective in many cases depending on the research objectives (Lee, 1991; Cavaye, 1996). The combination offers a multi-dimensional view of the subject gained through synergy. Thus it can be very powerful to gain insights and results, to assist in making inferences and in drawing conclusions (Fellows & Liu, 1997). Triangulation also gives an added dimension and adds considerable value to the research results, providing both breadth and depth (Moore, 2000). According to Fielding and Schreier (2001), there are three models of triangulation:

- **Validity Model:** Triangulation is the mutual validation of results obtained on the basis of different methods;
- **Complementary Model:** Triangulation is a means towards obtaining a large, more complete picture of the phenomenon under study; and
- **Trigonometry Model:** Triangulation indicates that a combination of methods is necessary to gain any picture of the relevant phenomenon at all.

There are two main categories in triangulation, including simultaneous triangulation and sequential triangulation (Bowen, 1996). Simultaneous triangulation uses both qualitative and quantitative methods at the same time, whereas sequential triangulation refers to the use of one method to plan the next method (i.e. both quantitative and qualitative methods are employed within one and the same study), although in different phases of the research process.

2.4. Approaches in Information Systems (IS) Research

The approach to be adopted for conducting the research, depends on the nature of the investigation and the type of data and information that are required and available (Naoum, 1998) . Galliers (1985) identified various research approaches which are used in the study of Information Systems (IS). These approaches and their typical application in IS research is summarised in Table 2-2, and is discussed in more detail in the following section.

Table 2-2: Research Approaches in IS (Adapted from Galliers et al, 1985)

Research Approach	Typical Application in IS
Action Research	<ul style="list-style-type: none"> To obtain practical results of value to groups with whom the research has allied itself while at the same time, adding to the body of theoretical knowledge
The Case Study Approach	<ul style="list-style-type: none"> To study IS failures or implementation efforts To study the impact of IT and IS on organisations. Research into the role and effects of IT and IS on society
The Survey Approach	<ul style="list-style-type: none"> To study IS failures or implementation efforts To study the impact of IT and IS on organizations. Research into the role and effects of IT and IS on society
Future Research	<ul style="list-style-type: none"> To study impact of IT and IS given different situations
Longitudinal Studies	<ul style="list-style-type: none"> Identification of changing relationships and their causes
Phenomenological Studies	<ul style="list-style-type: none"> To describe a situation being studied, with a view to producing results
Laboratory and Field Experiments	<ul style="list-style-type: none"> To improve the effectiveness of information systems in practice

2.4.1. Action Research

The action research involves active participation by the researcher in the process under study, in order to identify, promote and evaluate problems and potential solutions (Fellows et al, 1997). It 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). According to Eden & Huxham (1996), good and effective action research should have the following outcomes:

- It should have implications that relate to situations other than the one that is studied;
- It should be concerned with theory, as well as being usable in everyday life;
- It should lead to the generation of emergent theory; and
- It should have practical implications thus action researchers should be clear about what they expect participants to take away from the project.

One of the key advantages in undertaking the action research is that the researcher's bias is made overt in undertaking the research (White, 1985). Action research also places a great deal of responsibility on the researcher who must be aware that in certain circumstances (s)he is aligning herself/himself with a particular grouping whose objectives may well be at variance with other groupings (Galliers, 1985).

2.4.2. The Case Study Approach

Yin (1994) defines a case study as empirical inquiry based on observable evidence that investigates a phenomenon in a natural setting when the boundaries between the phenomenon and its context are not clear, using multiple sources of evidence. Its defining feature is the exploration of complex real-life interactions as a composite whole. According to Weiss (1998), a case study is a way of organising data so as to

keep the focus on totality. One who conducts case studies tries to consider the inter-relationships among people, institutions, events, and beliefs. Rather than breaking them down into separate items for analysis, the researcher seeks to keep all elements of the situation in sight at once. The strength of case studies lie in the fact that they allow for covering a large amount of ground for an acceptable cost (Fellows & Liu, 2003). In addition, it provides a means of looking in-depth at complex problems. Case studies can also help in achieving greater realism in the research. A key weakness of the case study method is that data collection and analysis process may be influenced by the researcher's interpretation of events, documents and interviews (Drake et al, 1998).

2.4.3. The Survey Approach

Surveys are used to gather data from a relatively large number of respondents within a limited time frame. It is thus concerned with a generalised result when data is abstracted from a particular sample or population (Naoum, 1998). Commonly samples are surveyed through questionnaires or interviews, and they vary from highly structured questionnaires to unstructured interviews. According to Naoum (1998), there are two types of survey:

- **The descriptive survey** aims to answer such questions as: How?, Many?, Who?, What is happening?, Where?, and When?. It deals with counting the number of respondents with certain opinions/attitudes towards a specific object.
- **The analytical survey** aims to establish relationships and associations between the attributes and objects of the questionnaire.

The key advantage of the survey approach is that a greater number of variables may be studied compared to the experimental approach. The key disadvantage is that little insight is usually obtained regarding the causes or the processes behind the phenomenon being studied.

2.4.4. Future Research

In this kind of research, different scenarios, or futures, are postulated and the different impacts of IT and IS are identified given these different situations (Galliers, 1985).

Table 2-3 summarises various approaches to design of future research.

Table 2-3: Research Methods for Future Studies (adapted from Glenn et al, 2003 & Galliers, 1985)

Research Method	Description	Typical Techniques
Future Extrapolation Methods	These methods are based on the belief that the future represents a logical extension of the past	Trend Analysis, Time Series, Regression, Econometrics, and Simulation Modelling
Exploratory Methods	These methods concentrate on structuring possible futures, typically using qualitative descriptions	Morphological Analysis, Relevance trees, Mind-mapping and Future wheel
Participatory Methods	These methods are based on expert and stakeholder opinions and insights about the future	Delphi Technique, Scanning, Focus Groups, and Future search conferences
Future Modelling	These methods describe the future by identifying the determining mechanisms of past events and how these influence the future	Analogy analysis, Technological sequence analysis, Stakeholder analysis and Structural analysis
Scenario-planning Methods	A key assumption is that future is essentially unpredictable. Considering the uncertainties included in the future, modelling will not lead into one future but rather to many different futures, each of which may be described in the form of a scenario	Scenario methods combine aspects of other tools with the aim of creating several scenarios
Normative Method	These methods investigate how we want the future to be and how to obtain this goal	Typical method is back-casting. Objectives that are very discontinuous from the present trends are defined and then the normative method moves backwards to the present to identify the necessary steps for reaching these objectives

2.4.5. Longitudinal Studies

Longitudinal studies involve repeated measures on the same variables for the same group or groups on an extended series of occasions (Robson, 2002). Babbie (1992) defined three types of longitudinal studies, including:

- **Trend Studies** examines changes within some general population over time;
- **Cohort Studies** examines more specific sub-populations over time; and
- **Panel Studies** examines the same set of people over time.

Longitudinal research uses two types of time design (Fellows & Liu, 2003), including discrete time design (in which cross-sectional data is collected on two or more occasions) and continuous time design (in which data is collected ‘continuously’ over a period). Quantitative methods of undertaking longitudinal research include social survey research (on a sample on more than one occasion) or content analysis of documents relating to different time periods. Qualitative methods of undertaking longitudinal research include ethnographic research over a long period, qualitative interviewing on more than one occasion, or qualitative content analysis of documents relating to different time periods (Bryman & Bill, 2003).

The key advantage of longitudinal studies is that it by-passes the problems associated with the identification of relationships at a particular point in time. Robson (2002) defined three major weaknesses of the longitudinal research, which include:

- **Sample attrition:** This happens when participants are lost to the study when follow-up measures are being made;

- **Need to devise measures which can be used repeatedly:** The nature and the type of measures need to be appropriate for use on several occasions with the same persons; and
- **Need for special methods of data analysis:** The analysis must take note of the implications of there being repeated measures.

2.4.6. Phenomenological Studies

Phenomenological studies aim to understand a particular phenomenon (Robson, 2002). The key focus is on the subjective experience of the individuals studied. The key advantages of this approach include:

- It recognises the fact that the researcher will interpret what is being studied in a particular way; and
- It provides a means of describing the inter-relationship of many factors found in real-life.

The key disadvantage of this approach is that despite making the prejudice of the researcher known, it could still cloud the interpretation of reality and thus make the research conclusions subjective (Galliers, 1985).

2.4.7. Laboratory and Field Experiments

Laboratory and field experiments were discussed previously in Section 2.3.2.2.

2.5. Research Approaches in Construction IT

According to Fellows & Liu (2003), the research methods which are most applicable to construction research include action research, surveys, case studies, experiments and ethnographic research. However, in the past decade, the number and the complexity of research methods available to construction researchers have increased sharply, particularly with the advent of information technologies (IT) focused research within the construction domain. Where only a few forms of inquiry were available (and acceptable within the scientific domain) previously, many options now exist (Kimmance, 2002). This proliferation allows for a wider choice to the researcher and better matching of the research tools to the demands of the research questions.

It is also important to realise that research in Construction IT differs from the study of IT as a purely technical phenomenon (Whyte, 2000). In Construction IT, the focus is not merely on technology. Rather issues with regards to appropriateness of the technology for various cultural and social factors specific to the construction industry should also be taken into account. In a critical review, Leslie (1996) highlighted that construction researchers see only the positive side of hard methodology approaches without taking into consideration the complexity of IT applications. They concentrate their research on technical aspects forgetting how IT can be accepted and used by the construction practitioners. This results in poor alignment of the technology with the construction industry's needs. In light of the aforementioned discussion, this research takes both the technology and application perspectives (explained in more detail in Section 2.7), to ensure that technology is rightly aligned to the needs of the industry.

2.6. Scenario-Planning Methods

Scenario-planning methods are considered very relevant to achieve the research objectives. This section reviews scenario-planning methods in more detail. According to Schwartz (1991) scenarios are descriptions of possible or probable futures. They are a vehicle for envisioning where the world could go so that we can learn in time to do something different. They are not projections, predictions or preferences. Rather they are coherent and credible stories, describing different paths that lead to the alternative futures (Davis, 2002). The underpinning philosophy of scenario-planning methods (Heijden, 1996) is that the future cannot be foreseen, but that some of the forces that will shape the future can. When these driving forces are identified and some of the ways they are likely to interact and affect other key variables are considered, then futures built by intuition and logic can be constructed (Verity, 2000). Thus scenario-planning facilitates thinking about the future, so that informed decisions can be made in the present.

The scenario-planning is not a single well-defined methodology but rather a set of principles for strategic analysis and planning that may be applied using a combination of various qualitative and quantitative research methods and techniques (Sideris, 2002). Disciplines and practices that have influenced scenario-planning include mental models, cognitive mapping, systems analysis, stakeholder analysis, conceptual thinking, decision analysis, facilitation techniques, oral tradition, and storytelling (Davis, 2002) (Figure 2-2).

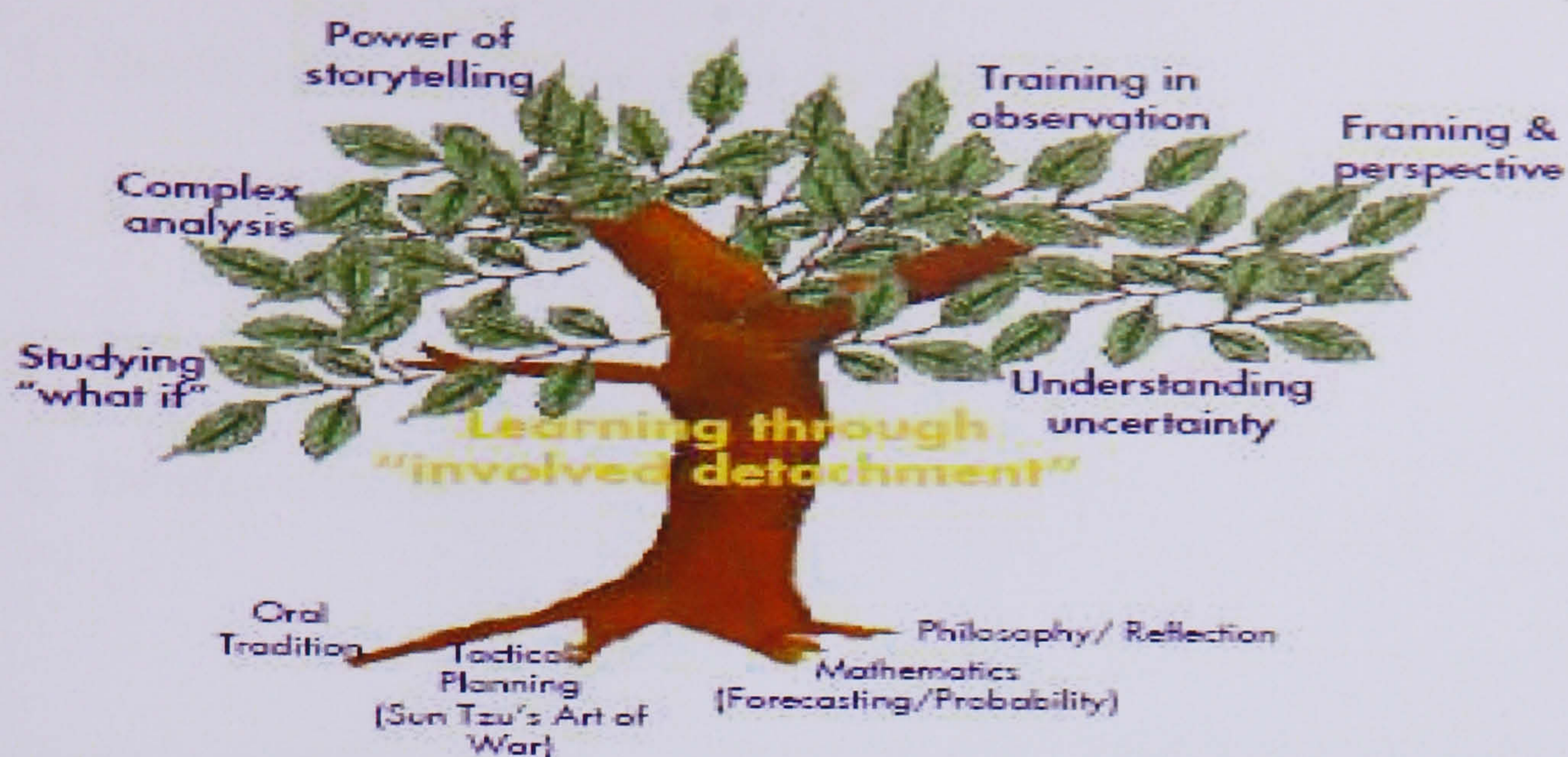


Figure 2-2: Roots of Scenario Thinking (Davis, 2002)

In Sections 2.6.1 and 2.6.2, two different scenario-planning methods are reviewed. These methods depict two extreme views on how the scenario-planning process should be approached. Section 2.6.1 discusses the Structural Scenario Method, which relies on the use of formal rules and techniques. Section 2.6.2. discusses the Peter Schwartz (1991) approach which is more informal, based on the key factors, the driving forces and the alternative visions gathered by a team of experts.

2.6.1. The Structural Scenario Method

This method was developed by Godet (2001) and is primarily driven by formal techniques, which are employed to reveal hidden relationships between variables, actors and hypotheses. The scenario construction is constantly backed up by formal rules and methods, to reduce the number of variables and actors and to test the probabilities of different hypotheses (Sideris, 2002). This method suggests six stages as follows (Godet, 2001):

1. Formulate the problem, examine the system;
2. Search for key variables, both internal and external;

3. Identify actors, strategic stakes and objectives;
4. Scan the field of possibilities;
5. Investigate the key questions for the future; and
6. Develop scenarios.

The research techniques used in the Structural Scenario Method include a mixture of facilitated group interaction (such as workshops) and formal quantitative techniques (such as structural analysis, analysis of actor's strategies and morphological analysis).

2.6.2. Peter Schwartz Approach to Scenario-Planning

Peter Schwartz in his book "The Art of the Long View" (Schwartz, 1991) proposed an eight-step methodology for scenario-planning. These steps include:

1. Identify the key issue that will influence the future;
2. Identify the key factors in the micro-environment;
3. Identify the driving forces in the macro-environment;
4. Rank key factors and driving forces by importance and uncertainty;
5. Select scenario logics;
6. Flesh out the scenarios;
7. Draw implications; and
8. Select leading indicators and signposts.

This method starts by identifying particular key factors and driving forces, which are the elements that move the plot of a scenario. Although the method does not rule out completely the use of other formal techniques (as used in the Structural Scenario

Method), it relies almost entirely on the facilitator to mediate productive debate within a group of experts. In this sense, it is a highly informal approach (Sideris, 2002).

Section 2.7.2 include a justification for choosing scenario planning method for this research.

2.7. Research Methodology Adopted and Justification

Figure 2-3 illustrates the key steps in the research process, while Table 2-4 presents tools used in various research steps. Various research steps and tools used are discussed in more detail in the following section.

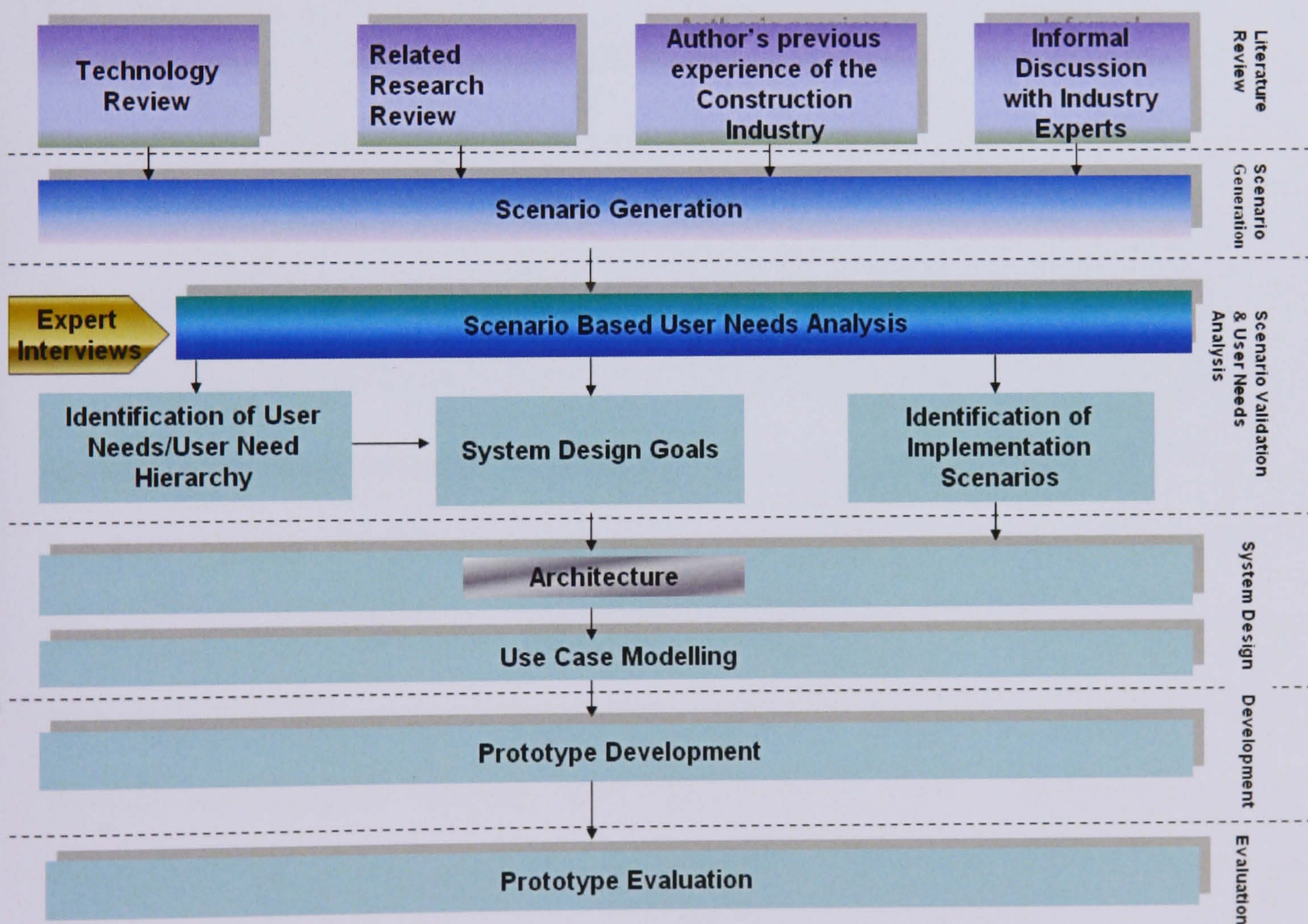


Figure 2-3: The Key Research Steps

Table 2-4: Tools used in various research steps

Research Tools Research Tasks	Technology and Literature Review	Scenario Generation	Scenario Validation	User Needs Analysis	System Design	System Development	System Evaluation
Personal Document Analysis (explained in Section 2.7.1)	√						
Semi-Structured Interviews (Using Laddering Technique) (explained in Section 2.7.3)			√				√
Scenario-planning Method (explained in Section 2.7.2)		√					
Scenario Based User Needs Analysis (explained in Section 2.7.3)				√			
Use-case modelling (explained in Section 2.7.4)					√		
Rapid Prototyping (Explained in Section 2.7.5)						√	

2.7.1. Technology and Literature Review

The technology and literature review involved a state-of-the-art-review of developments and trends in context-aware computing. Primary data was sourced from academic journals, conference proceedings, articles, books and from various on-going research projects. A referenced summary was prepared, which is presented in Chapters 3 and 4. The technology and literature review was based on ‘personal document analysis’, a qualitative analysis approach to review and analyse current theories and literature (Keppel, 1991; Dainty et al, 1997). The technology and literature review also addressed “how” and “why” questions related to the relevance of various enabling technologies for supporting mobile construction workers.

2.7.2. Scenario Planning Method

The encompassing theme of this research is the emerging field of context-aware computing, and its future applications for the construction industry. From this viewpoint, various future research methods (as discussed in Section 2.4.4) are considered very relevant to achieve the research objectives (as described in Section 1.6). Of the various future research methods discussed in Table 2-3, scenario-planning and participatory methods are considered the most relevant for this research. The emerging nature of the context-aware technologies and the huge amount of uncertainties with regards to application in the construction industry (such as application scenarios, business models, technology robustness, interoperability and costs) undermine the basic assumption of the future extrapolation method (i.e. the future represents a logical extension of the past) and future modelling method (i.e. the future can be modelled based on the events of the past). Also, a recent review of future forecasting techniques (such as future extrapolation and modelling methods) as applied to telecommunications strongly criticised their adequacy to predict new products and services in uncertain conditions (Fildes et al,2002). Normative methods are not considered relevant for this research because of their underlying assumption that there is a one single right future with the consequence of aiming to deduce it. In contrast, because of the high level of uncertainties involved with regard to context-aware technologies applications in the construction industry this research effort relies on the scenario-planning assumption that there is no single best answer since the future is uncertain and unpredictable (Heijden, 1996). The scenario-planning method is considered the most appropriate for uncertain, complex and fast developing situations where the future cannot be predicted accurately enough to identify a single forecast and it cannot be reasonably expected to be a continuation of present and past trends (Godet 2001; Dyson 1990). Also, scenarios are known to offer greater

advantages over other forecasting methods when uncertainty is high and historical relationships shaky (Fahey & Randall, 1998). The key disadvantage of scenario-planning approach is that developing initial set of scenarios is a lengthy and time-consuming process. The scenario-planning method is discussed in more detail in Section 2.6. Participatory methods (as described in Table 2-3) are also considered relevant for this research because it is important to have the construction industry experts' and end-users' perspectives and insights about future context-aware information delivery.

2.7.2.1. Justification for Choosing Scenario-Planning Method

This research uses the scenario-planning method as the basis for understanding user-needs and for system design. This section explains different reasons for choosing scenario-planning methods for this research:

- **Scenarios Open up New Areas of Thinking:** Telling stories have always been considered a good way to get a group of people to think “out of the box” and to synthesise their inspiration and experience into a logical whole (Helvert, 2003). A key assumption in scenario-planning is that there is no single best answer but a broad space of future possibilities (Heijden, 1996). Unlike forecasts, which box-in-the-future, scenarios open up new areas of thinking and perspectives, so that the whole exercise can also be seen as one of stimulating creative foresight, even if no one scenario applies perfectly (Sideris, 2002).
- **Scenario-Planning is Suited for Complex and Uncertain Situations:** One key challenge facing this research is the fast pace of technological development and the complexity of context-aware wireless Web applications. Scenario-planning is particularly well suited to address high levels of complexity and uncertainty

(Dyson, 1990). According to Schoemaker (2001) in the study of emerging technologies, there are three particular challenges - uncertainty, complexity and paradigm shift - that can hardly be answered by other forecasting techniques.

- **It is Easy to Communicate a Scenario:** A context-aware service is a multi-disciplinary product of research from different fields including computer science, telecommunications, system design and ergonomics. Very often, different disciplines involved in the value chain (e.g. technology providers and end-users) use different terminologies and often ideas are not well understood by end-users. The construction industry experts have the most comprehensive knowledge about the construction industry dynamics (i.e. the construction industry pull). However, as a result of increasing the convergence and greater pace of technology growth, it is possible that these experts are not fully aware of the possibilities offered by emerging and converging technologies (i.e. the technology push). In order to investigate future context-aware services for the construction industry, it is important to have a deeper understanding of both the technology push and the industry pull, as the industry pull will define whether a technology push will succeed or not. For these reasons, visual description of technology implementation scenarios in real construction situations were chosen as the best method to test scenarios with industry experts at an early stage, prior to the system implementation.
- **Appropriate for use in the System Development Process:** Scenarios can be very effectively used in the system development process for many purposes (Weidenhaupt et al, 1998). These include:
 - To provide a long-range vision that stimulates ideas and directs short range goals;

- To focus the development perspectives on the users' point of view;
- To provoke and capture design decisions;
- To involve users in design decisions and requirements analysis;
- To validate the system specification and requirements analysis; and
- To serve as trial and evaluation experiments.

In this research scenarios are used to study the construction industry's needs and as a key input to system design process.

- **Previous Applications in Similar Research:** Previously scenario-planning techniques have successfully been used in future study exercises in mobile computing and their use is recommended for research in this area (Sideris, 2002). Some of the previous projects in the realm of mobile computing, which have employed scenario-planning are described as below:
 - In the MobiCom Project, scenario-planning techniques were used to develop scenarios for Mobile Commerce in 2006 (Aarnio et al, 2002);
 - In the 4GW project (Karlson et al, 2003), scenario techniques were used for studying next generation wireless applications; and
 - In Telecom 2010 (Flament et al, 1998) scenarios were created to generate awareness of plausible futures and to identify reasonable research assumptions.

The application of the scenario-planning method in the aforementioned projects also demonstrates applicability of the research methodology for mobile IT research.

2.7.2.2. Scenario Generation Process

As discussed in the last section, of the various research methods reviewed, scenario-planning was considered the most appropriate to achieve the research objectives. The key challenge in applying the scenario-planning method was to generate an initial set of scenarios for the application of context-aware technologies in realistic construction situations. The idea was to use these scenarios as the basis, to spur new ideas and themes and to understand the construction industry's needs for future context-aware technologies.

Several methods for scenario generation have been suggested by different authors and there is no single way of constructing a scenario nor can the same method be applied similarly in all cases (Masini et al, 2000). The scenario generation method used in this research was inspired by the Peter Schwartz's (1991) approach (as discussed in Section 2.6.2). Schwartz's approach to scenario-planning is relatively less prescriptive and offers a greater level of flexibility compared to other approaches (such as the Structural Scenario Method, as discussed in Section 2.6.1). The first step in the Schwartz's (1991) scenario generation approach is to identify the factors and trends that will influence the future. As identified by Fahey & Randall (1998), the identification of the key factors and trends can generally be done in two ways:

- **Future Forward Method:** This approach is based on the future extrapolation methods. Based on the events of past and present, the future is modelled.
- **Future Backward Method:** This involves imagining the future or aspects of the future and then deducing the underlying factors or forces driving that development.

For this research, the “Future Backward Method” was chosen. There were essentially two reasons for choosing this method. Firstly, given the emerging nature of context-aware computing research, it was not possible to develop future scenarios based on the existing applications. Secondly, the “Future Backward method” allows more room for creativity and visionary thinking. Cole et al (1978) described three possible source of the initial set of scenarios:

- **Analyst Input:** The analyst doing the study generates the scenarios based on their experience and research;
- **Expert Input:** Expert informants contacted by the analyst contribute ideas in various ways such as via free-form discussions, interviews, Delphi procedures, workshops, or other techniques;
- **Analyst and Expert Input:** This method combines both analyst and expert informant input.

The third method (analyst and expert input) was adapted for this research. The aim was to use previous scientific research as the basis of scenario generation process. The literature review (Chapters 3 & 4) was used to systematically gather information about the state-of-the-art in context-aware computing. A series of informal discussions with experts (both academic and industry) were also used to help shape the initial set of scenarios. Also, previously published literature with regards to information requirements of mobile construction workers (e.g. COMMIT, 2005; Garza et al, 1998; Bowden & Thorpe, 2002; Rebolj et al, 2002) was reviewed. Thus a combination of analyst and expert input and the study of context-aware computing and enabling technologies (presented in Chapters 3 & 4) were used to develop realistic user scenarios, in which the capabilities of various technologies were mapped to the information needs of mobile construction workers. Scenarios were set in a “day

in the life of' situations of a mobile construction worker and were generated to serve typical information needs (such as procurement of goods, project management, services provision, task details). The key objective of generating realistic construction scenarios was to take the focus away from the underlying technology and to find out more about the key drivers and barriers and utility of a particular application from the construction industry perspective. It is from an understanding of these problems that a list of user needs was drawn-up (presented in Chapter 6). The time horizon chosen for the scenarios was 10 years. Given the existing uncertainties involved with various enabling technologies (such as the Semantic Web, Web Services and Mobile Communications), this time frame was considered realistic. This long term focus was also important to ensure that the industry takes the right steps, in the short term, to effectively adapt to the emerging technologies in the long term. The scenarios are presented in Section 5.2.

2.7.3. Scenario Validation

In order to have a more credible and concrete validation of scenarios and to elicit different perspectives, interviews were conducted with industry experts. The key objective of scenario validation was to pose the question of the next generation context-aware mobile applications in the construction sector and to identify the industry's needs and application areas with the maximum potential. For the validation purposes, face-to-face unstructured interviews were arranged with 13 industry experts. Section 5.4 further elaborates on the scenario validation method.

2.7.4. System Design

As discussed in Section 2.5, it is important that the design of Construction IT systems should address the key issue of how these IT systems will be accepted and used by the construction industry practitioners. To address such concerns, various system design methods used in Human Computer Interaction (HCI) research (such as user needs assessment and task analysis, ethnographic methods, controlled experiments, survey and questionnaire methods) were reviewed. In HCI research, computing systems are usually built and tested for performance in relation to the human users. Also, in HCI research, usually a research effort starts by examining the demands and constraints of human operators in the applicable domain. During the testing stage, the system is tested relative to the user requirements.

In this research, the Scenario-based User Needs Analysis (SUNA) (Helvert et al, 2003) method was used to translate the user needs identified during the Scenario Validation process (Section 2.7.3) into system design goals. According to Helvert et al (2003), the SUNA method can be applied to “any situation that requires innovative thinking and is not limited by a large number of legacy constraints”. Previously the SUNA method had been applied for user-centred research and design projects (e.g. Brady et al, 2003). In this method, user needs are extracted from the scenarios. These needs are subsequently combined into a common table and a “Needs Hierarchy” is generated, which serves as the basis for the system specification. In this research, feedback gathered during the validation process was used to establish industry’s needs. Identified needs were then mapped to available technologies, resulting in a

communications system architecture and deployment models (i.e. use-cases based on UML). The method used for system design is explained in more detail in Chapter 6.

2.7.5. Prototype Development

This task involved the development of the prototype system using a construction industry context to demonstrate the system functionality. The prototype was developed on a Pocket-PC platform and the implementation environment was Microsoft VisualStudio.net. The prototype was not entirely a bespoke development. It has long been recognised in software engineering communities that developing a new system from scratch is expensive in terms of time, money and effort. Also, it is error prone and too expensive to maintain (Apperly et al, 2003). Thus off-the-shelf components were used for services delivery and location based tracking, as they satisfied the design criteria. Chapter 7 presents the prototype development and operation.

2.7.6. Evaluation

The prototype was evaluated in terms of its appropriateness for the construction industry and the implementation approach. This involved expert and end-user evaluation and a workshop, which is explained in more detail in Chapter 8.

2.8. Summary

The first part of this chapter presented general research methodologies, in order to provide the background understanding for the research method adopted in this research. The second part presented the research method adopted in detail for each task carried out during the project. This includes a technology and literature review on context-aware technologies, development of futuristic context-aware scenarios in the construction industry context, validation of these scenarios with the construction industry and technology experts, identification of the user needs, development of the prototype system based on these needs and evaluation of the prototype system. The next chapter presents key concepts and a framework for context-aware information delivery.

Chapter 3: Context-Aware Information Delivery

3.1. Introduction:

This chapter defines the concept of context-aware information delivery and reviews related work in this area. It explains in detail the technology concepts related to context-aware computing such as location-based services, user profiling, ubiquitous computing, RFID and wireless sensor networking. Various context-aware information delivery frameworks are reviewed and the WiSeCon framework is presented which aims to create a pervasive, user-centred mobile work environment, with an ability to provide highly specific data and services to mobile construction workers on as-needed basis. This chapter concludes with a summary of main points.

3.2. Context-Aware Information Delivery – Key Definitions

3.2.1. Definitions of Context

“Context” is a relatively new term in Information Systems research. Several authors have defined the term in the following ways:

- Context is location, identities of nearby people and objects, and changes to those objects (Schilit & Theimer, 1994);
- Context is a location, identities of the people around the user, the time of the day, season, temperature, etc. (Brown et al, 1997);
- According to Schilit, Adams and Want (1994), the important aspects of context are: where you are, who you are with, and what resources are nearby?;

- Pascoe (1998) defined context to be the subset of physical and conceptual states of interest to a particular entity.

The above definitions imply that key elements of context include the user-location and the immediate environment surrounding the user. Some of these elements (such as user-location, user environment) are constantly changing. However, some of the aforementioned definitions are too specific and do not include all possible context-dimensions that may be required to support mobile construction workers. For instance, if one wants to determine whether the task a mobile worker is currently involved in or the existing project conditions constitute a mobile worker's context or not, it is not clear as to how the aforementioned definitions can be used to answer such questions. On other hand, some researchers have defined context in a very generic term. For instance:

- Ward et al (1998) defined context as “the environment or situation”;
- Dey et al (2001) defined context as a “piece of information that can be used to characterise the situation of participants in an interaction”;
- Context constitutes a “set of environmental states and settings that either determines what an application behaviour is or where the event occurs”. (Chen and Kotz, 2000).

Such definitions define context in broad and generic terms and are difficult to apply in practical terms.

3.2.2. Context-Aware Applications

In the scientific literature, there are various terms used for context-aware applications (such as context-aware computing, situated computing, context-sensitive computing, situation-dependent computing). However, these terms refers to the same concept i.e.

the ability of applications to respond to their environmental situation (such as location, time, etc) Different definitions of context-aware applications are presented below:

- Context-aware applications dynamically change and adopt their behaviour based on the context of the application and the user (Cooperstock et al, 1995);
- Context-aware applications monitor input from environmental sensors and allow users to select from a range of physical and logical contexts according to their current interests and activities (Ryan et al, 1998);
- Context-aware applications use environmental characteristics such as the user's location, time, identity, profile and activity to inform the computing device so that it may provide information to the user that is relevant to the current context. It enables a mobile application to leverage knowledge about various context parameters such as who the user is, what the user is doing, where the user is and what terminal the user is using. The application adapts services to the interpreted context, thereby ensuring that the busy user gets highly specific data and services, relevant to the task at hand (Schilit et al, 1994);
- Context-aware applications are applications that use context to provide relevant information and/or services to the user, where relevancy depends on the user's task (Dey, 2000).

3.2.3. The Concept of “Context-Aware Information Delivery” in this Research

The concept of “context-aware information delivery” as discussed in this research centres on the need to provide mobile construction workers with highly specific information and services on an as-needed basis, by intelligent interpretation of their context. This concept goes beyond merely capturing various context parameters (such

as user-identity, user-location, user task). Rather, it encompasses the creation of a pervasive, user-centred mobile work environment, capable of supporting mobile construction workers by intelligent interpretation of their environmental situation, thereby helping them to take more informed decisions.

The use of context-awareness enables mobile applications to enhance user experience by delivering only the relevant information. Using context-aware information delivery, it is possible to eliminate distractions for mobile workers, related with the volume and level of information. Also, user interaction with the system can be reduced by using context as a filtering mechanism to deliver information relevant to the task at hand. This has the potential to increase the usability, by decreasing the level of interaction required between the mobile devices and the end-users (Aziz et al, 2005-b). The emergence of complementary technologies such as user profiling, ubiquitous computing and sensor networking enables the capture of many other context parameters.

3.2.4. Context Parameters

Pashtan (2005) described four key partitions of context parameters, which are often used in context-aware applications. These including user static context, user dynamic context, network connectivity and environmental context, and are illustrated in Fig 3-1. While, the context dimensions identified by Korkea (2000) included identity, spatial information (i.e. location), temporal information (i.e. date and time of the day), environmental information, social situation (i.e. who you are with and people that are nearby), schedules and agenda, current activity and availability of resources. Section 3.5.2 defines the context dimensions addressed in this research.

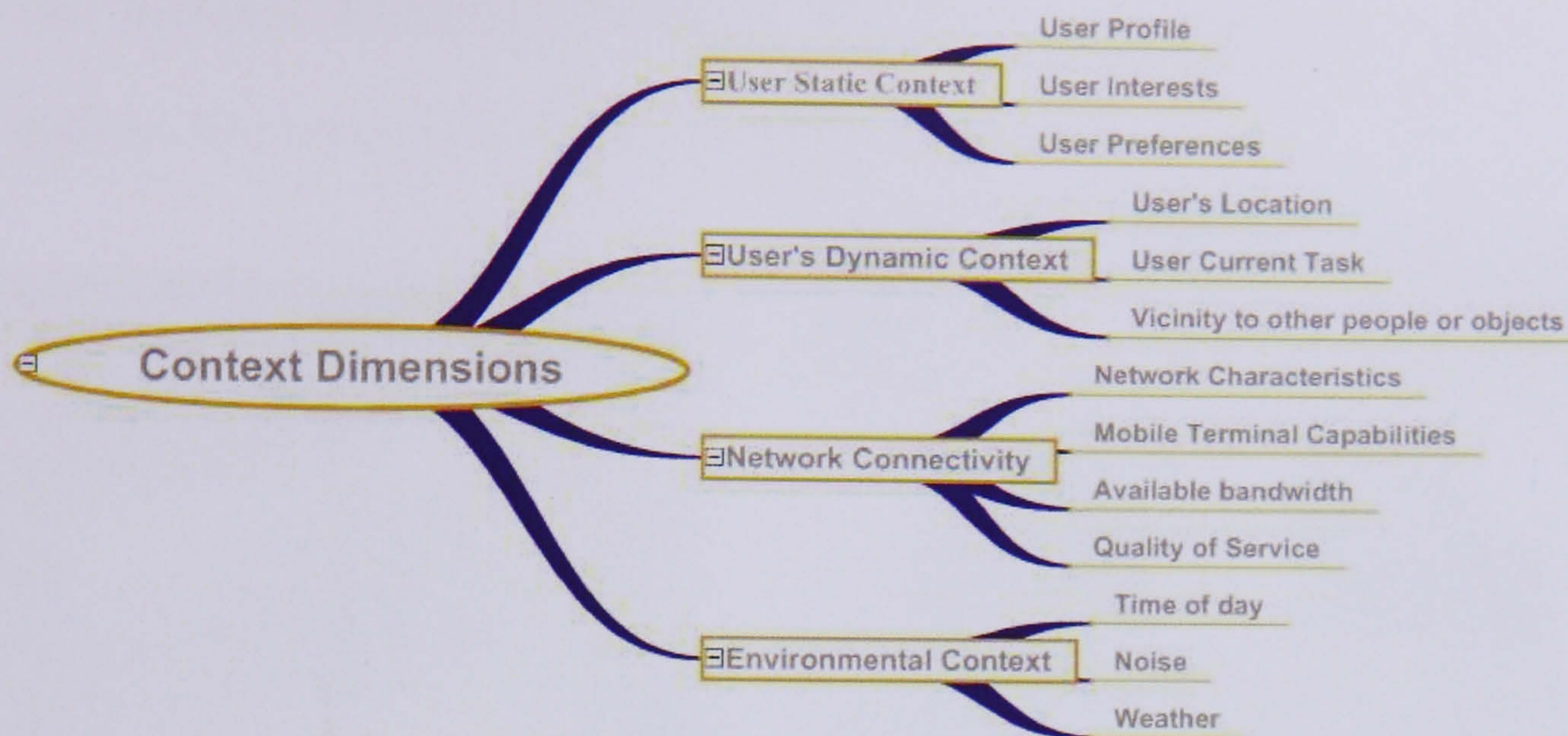


Figure 3-1: Context Dimensions (Pashtan, 2005)

3.3. Context-Aware Computing - Related Work

The context-aware computing is an established area of research within computer science. The application of context-awareness for mobile users has been demonstrated in a large number of applications, including fieldwork (Kortuem et al, 1999; Pascoe et al, 1998), museums (Fleck et al, 2002), route planning (Marmasse et al, 2002), libraries (Aittola et al, 2003), meeting rooms (Chen et al, 2004), smart-houses (Coen, 1999) and tourism (Long et al, 1996; Laukkanen et al, 2002). Location is a key context parameter and other projects that have specifically focused on the location-based data delivery included Mobile Shadow Project (MSP) (Fischmeister et al, 2002) and the GUIDE project (Davies et al, 1999). The MSP approach was based on the use of agents, to map the physical context to the virtual context. While, the Guide project focused on location-aware information provision to tourists. The system (Fig 3-2) was Internet based and its adaptive elements were designed to respond to the user profile,

collected geo-location information and navigational aides. Visitors interacted with the system using tablet PCs connected to information servers over IEEE 802.11 wireless local area networks. Location information was retrieved via cell ID of wireless LAN base stations. The accuracy provided by the system was 200 metres.

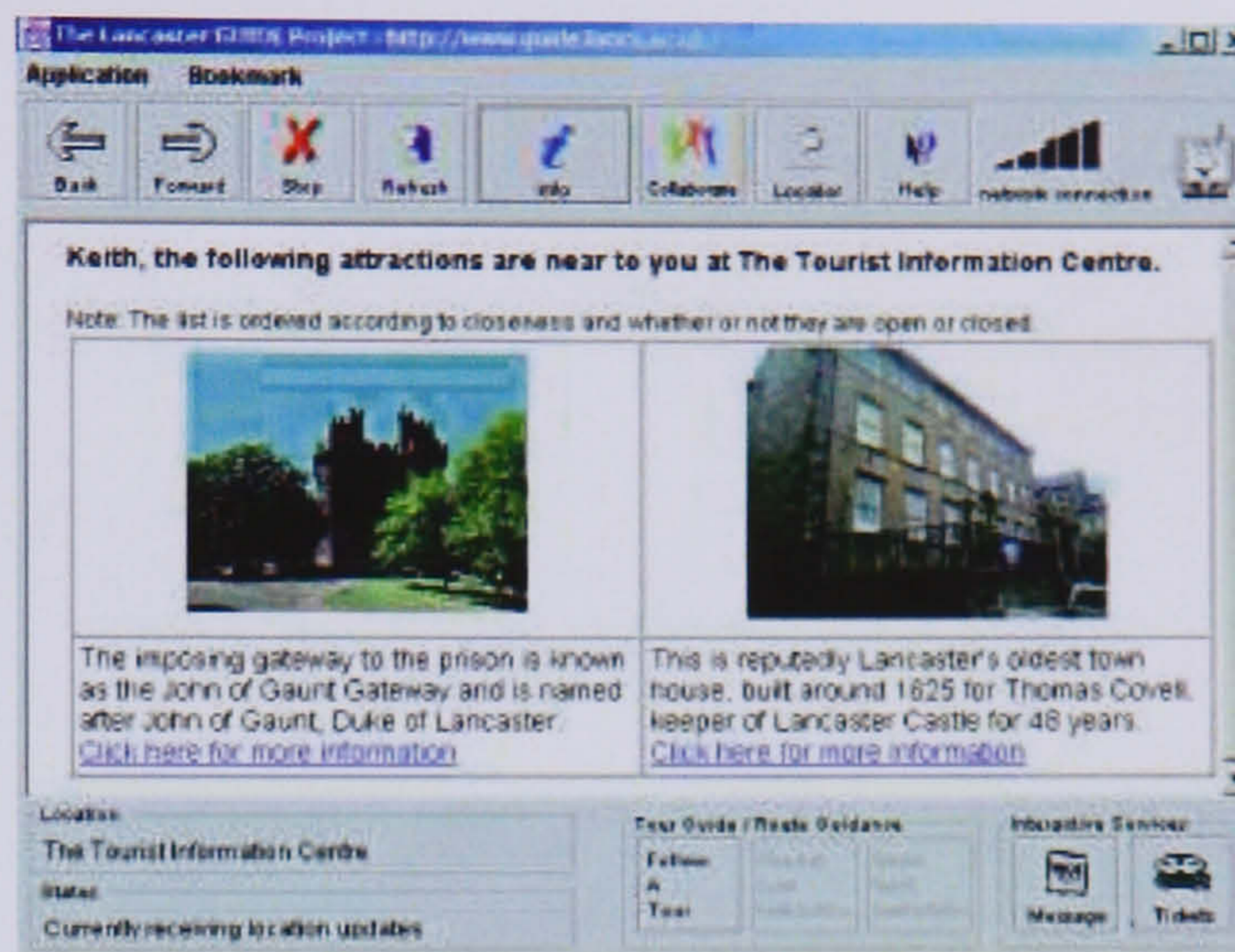
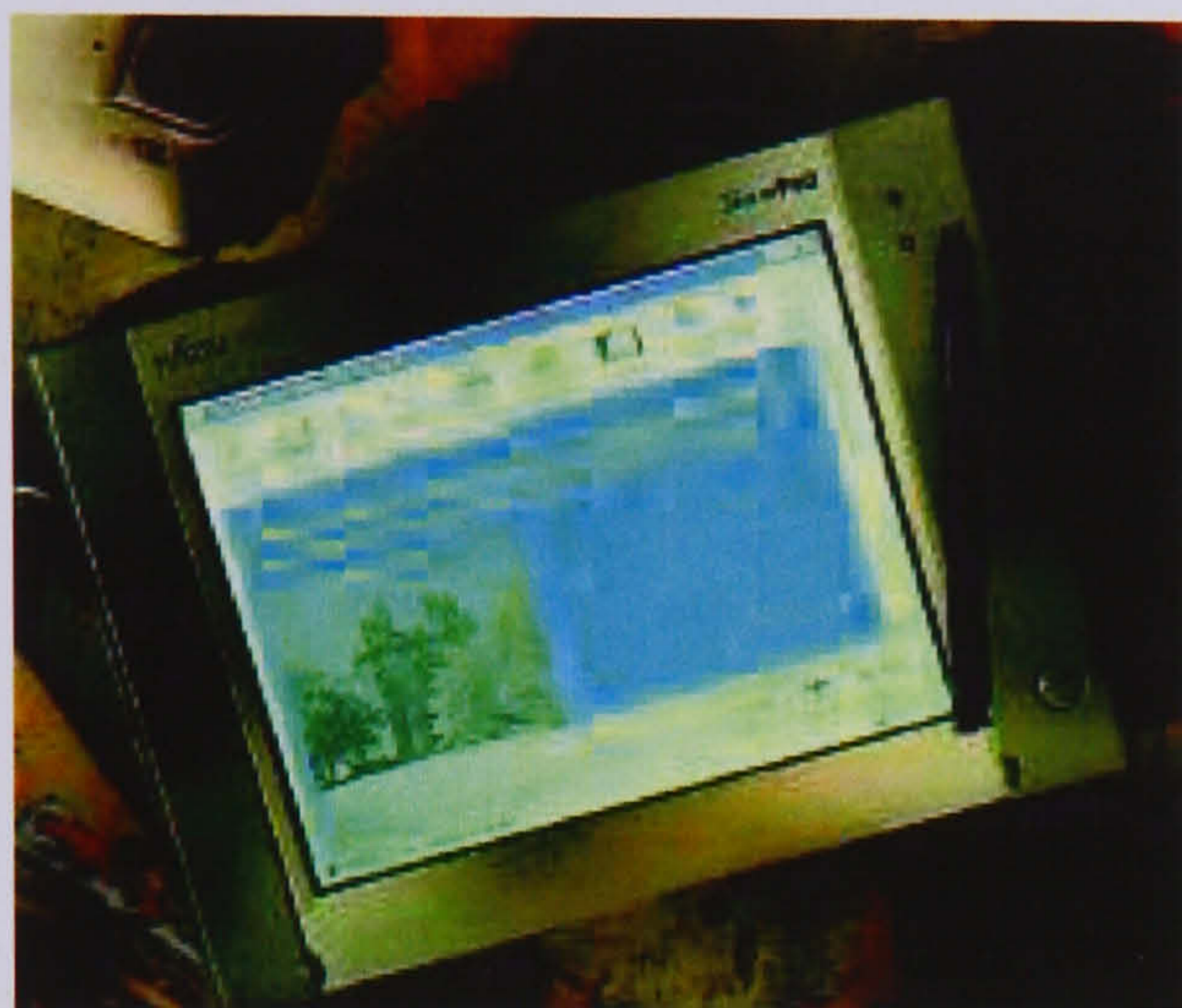


Figure 3-2:Lancaster's Guide: (a) user device, and (b) localised info delivery (Davies et al, 1999)

In the Ambience Project (Ambience, 2005) a different approach was adopted by focusing on creating a tag based digital environment that is aware of a person's presence, context, and sensitivity and responds accordingly. Lonsdale et al (2003) implemented a prototype to facilitate mobile learning. In the implementation, mobile devices pass contextual information obtained from sensors, user input, and user profile to the context subsystem. The context sub-system then compared this metadata to the content metadata provided by the delivery sub-system and returned a set of content recommendations (Fig 3-3). These recommendations were then used by the delivery subsystem in determining which information to deliver.

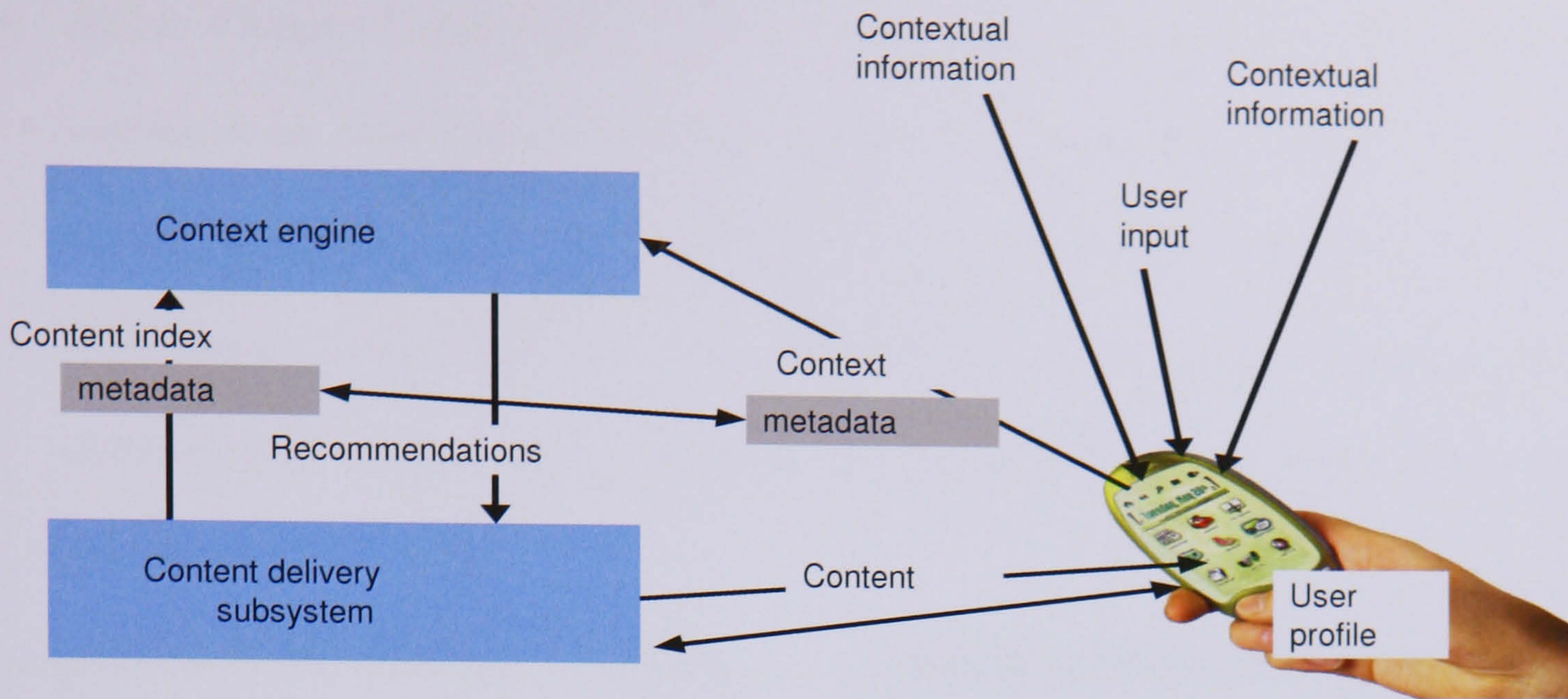
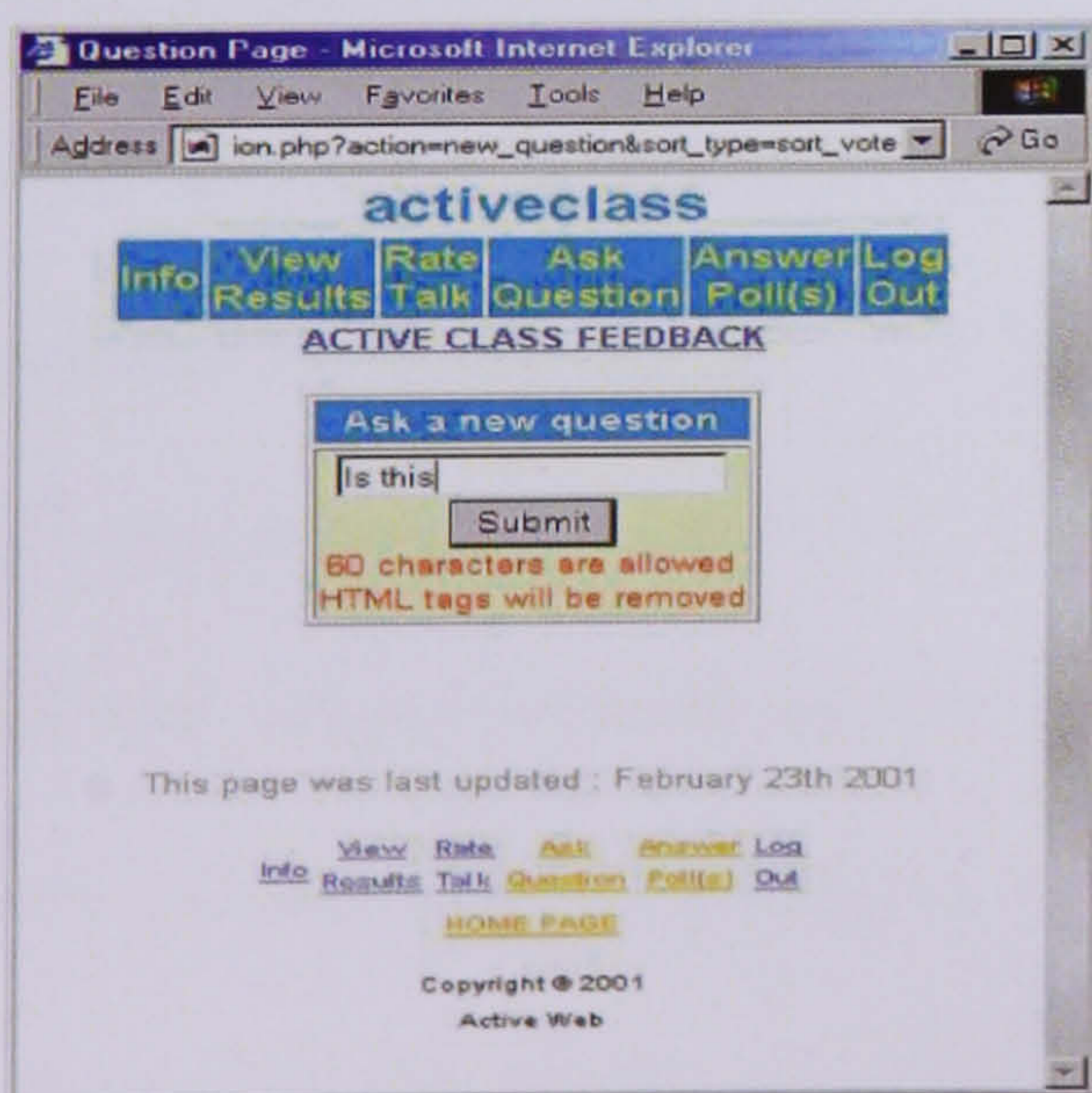


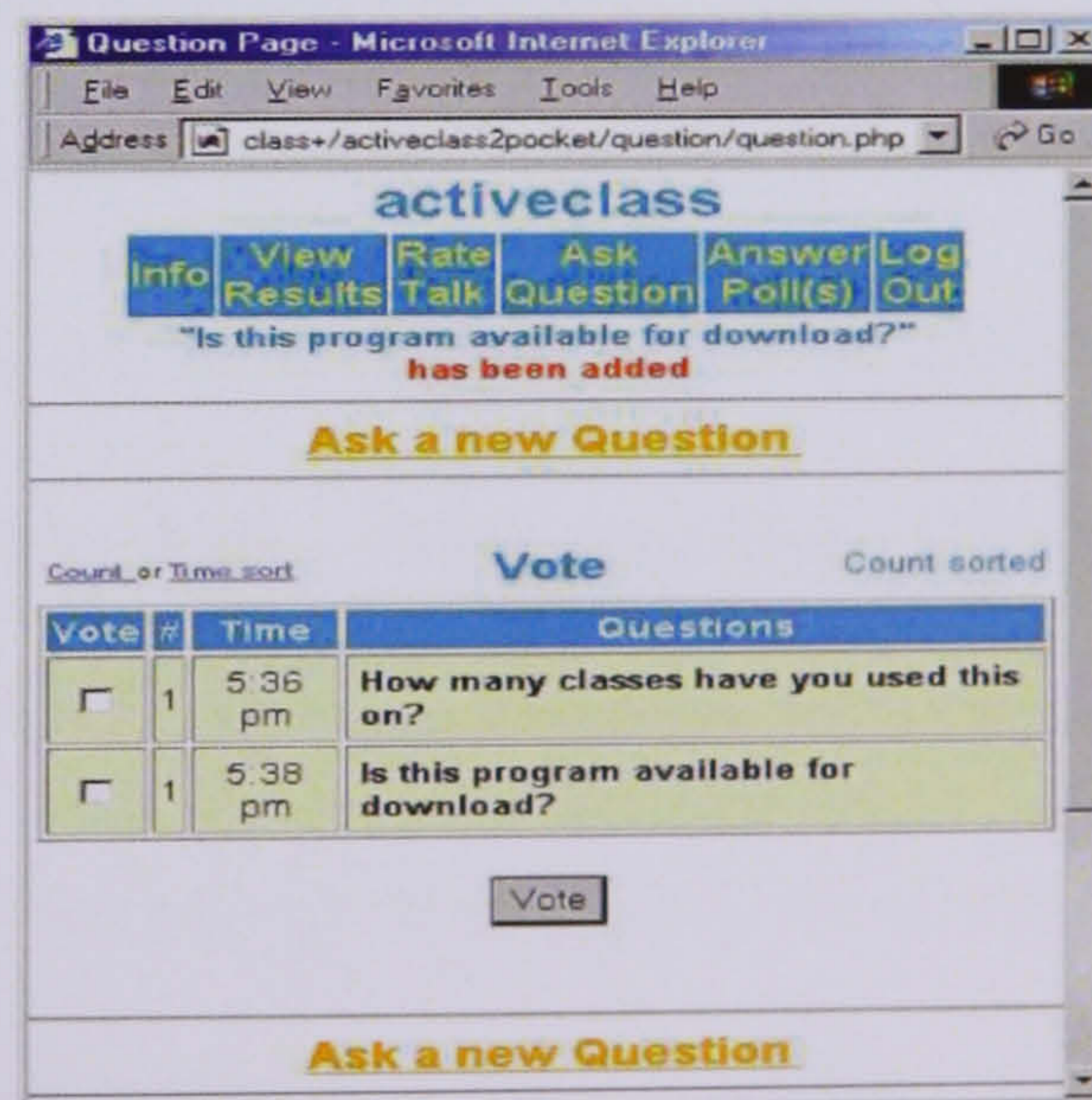
Figure 3-3: Context-aware System Architecture (Lonsdale et al (2003))

In the Active Campus project (Griswold et al, 2002), a prototype was developed, to demonstrate the potential of context-aware information delivery technology to support staff and students in an education setting. The system comprised two main components i.e. Active Class and Active Campus Explorer.

- Active class (Fig 3-4) was a Web-based system, designed to encourage classroom participation. It used PDA as a complementary channel to lectures. Class members were identified by their location in a particular classroom. To avoid misuse, person to person communications were not supported.



(a)



(b)

Figure 3-4: ActiveClass user interface and discussion aggregator (Griswold et al, 2002).

- Active Campus Explorer (Fig 3-5) was designed to provide users the ability to communicate with nearby colleagues using a purpose built instant messaging system. It also provided a means to annotate physical locations with hyperlinks to Web pages. It used location, time, personal interests and hyper-linking to Web documents to notify users of nearby interesting activities or other source of information.

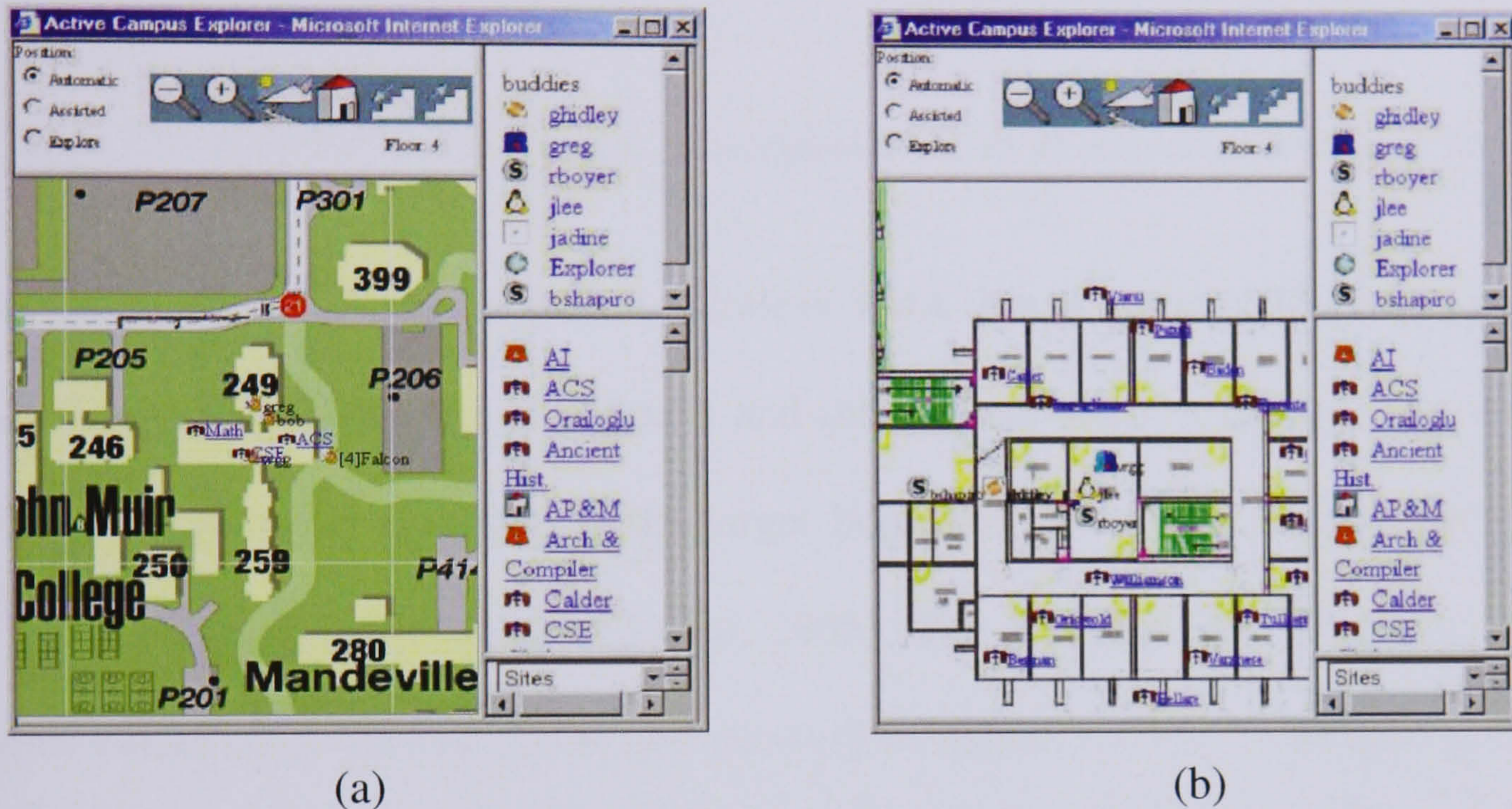


Figure 3-5: Active-Campus Explorer: (a) Outdoors and (b) Indoors view (Griswold et al, 2002).

In a similar piece of work (Arnstein et al, 2002), location-aware technologies were used in a laboratory environment to first collect and organise data where and when created and then make this information available where it is needed (Fig 3-6). Proximity to a particular object or location was sensed either via RFID badges or via direct contact with a touch screen. Each researcher in the laboratory was given a RFID badge that uniquely identified him. This unique identifier provided authentication for access to laboratory applications as well as triggering the migration of the user interface from one display to another closer to the position of the researcher.

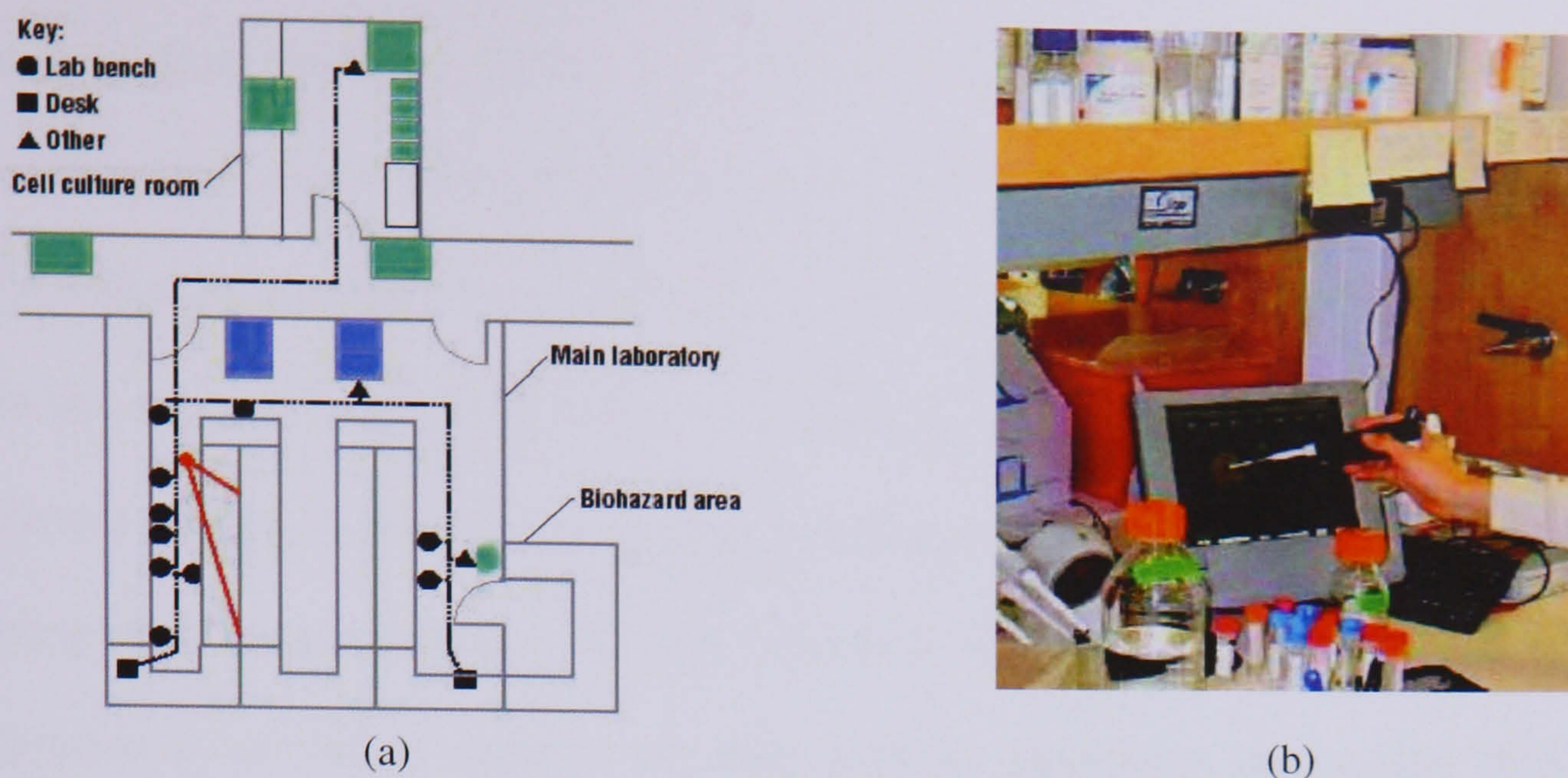


Figure 3-6: (a) tracking a researcher and (b) workbench with RFID sensors (Arnstein et al, 2002)

Aittola et al (2003) developed a wireless PDA based system (Fig 3-7) called SmartLibrary to help users find books and other materials in a library. The system provided map-based guidance to the target bookshelf on a PDA, using a Wireless LAN-based positioning engine (Ekahau, 2005). The guidance was integrated to the online library catalogue, so that books retrieved from the catalogue could be located.

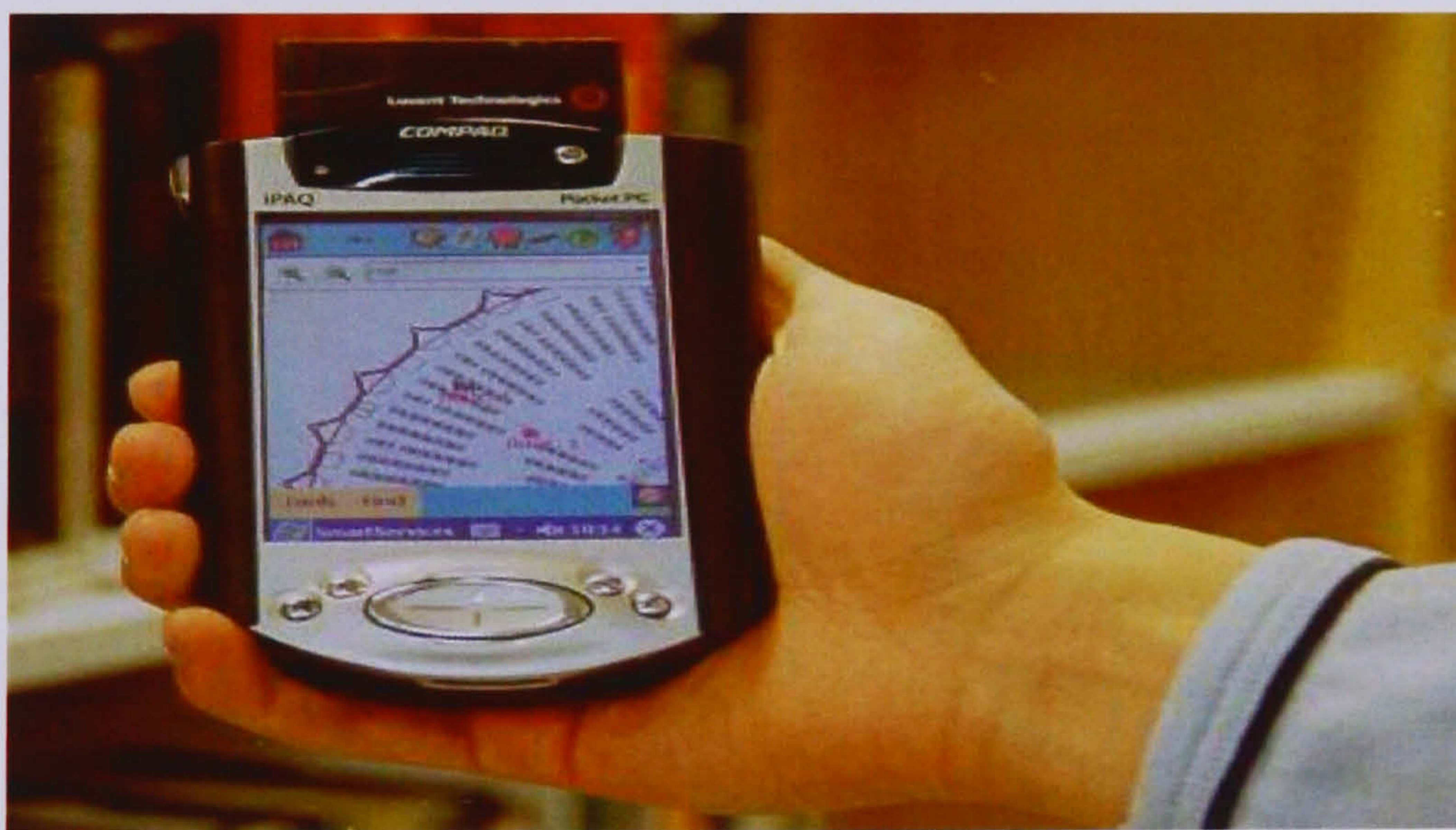


Figure 3-7: Smart Library System-Interface (Aittola et al, 2003)

Context-aware applications are also being investigated by other fields of research in computer science, including mobile, ubiquitous and wearable computing, augmented reality and human computer interaction. However, the application of context-aware technology in the construction industry remains limited (Aziz et al, 2005-b). As can

be seen from the above review, most of the context-aware applications rely on user location and user-preferences to determine user-context. Section 3.4.1 and Section 3.4.4 discuss the concept of location-based service delivery and user-profiling in more detail. Also, an interesting trend in context-aware computing research is the use of sensors or tags attached to objects (for identification and sensor data capture) and the integration of sensors/tags with other elements of context (e.g. Arnstein et al, 2002; Aittola et al, 2003). Related concepts such as ubiquitous computing, RFID and wireless sensor networking are discussed in more detail in Section 3.4.2, Section 3.4.3 and Section 3.4.4 respectively.

3.4. Context-Aware Computing- Related Concepts

3.4.1. Location Based Services:

Location is an important, and the most widely used, aspect of context-aware frameworks (Smailagic & Kogan, 2002). The term location-based services refers to applications that utilise the knowledge of the user/object location to provide relevant information and services. From the viewpoint of the construction industry, accurate and timely identification and tracking of construction components are critical to operating a well-managed and cost efficient construction project (Furlani et al, 1999). A variety of different location-tracking technologies exists with significantly different characteristics, different infrastructure and device requirements. Some of these technologies are reviewed in Table 3-1.

Table 3-1: Location-Tracking Technologies

Technology	Description
Active-Badge (Hightower et al, 2001)	Active-Badge system uses infrared emissions emitted by small infrared badges, carried by objects of interest. A centralised server receives the emitted signals and provides the location information.
Active-Bat System (Hightower et al, 2001)	The Active-Bat system resembles the Active-Badge system, except that it uses an ultra-sound time-of-flight lateration technique for higher accuracy.
Cricket System (Nissanka et al, 2000)	The cricket system relies on beacons, which transmit radio frequency signals and an ultrasound wave. Receivers are attached to the objects and they estimate their position by listening to the emissions of the beacons and finding the nearest one.
Smart-floor (Hightower et al, 2001)	The smart-floor technology utilises pressure sensors to capture foot-fall in order to track the position of a pedestrian
Global Positioning Systems (GPS) (Sacks, 2003)	GPS is an out-door positioning technology that allows its users to determine their exact location, using orbiting satellites, which are spaced, so that at any point on earth, a minimum of four satellites are on the horizon. The GPS receiver on earth receives signals broadcast from the satellites. With the changing position and their time, the receiver can triangulate its exact position, resulting in longitude and latitude determination.
Radio-Transmission Based Positioning Technologies	These technologies use signal strength and triangulation to determine client location. These technologies are appropriate for positioning within built structures. Some of these technologies operate in a free-spectrum (e.g. 2.4 GHz) such as Bluetooth and WLAN while others are based on dedicated spectrums (such as RFID or Dedicated Spectrum-based positioning).

As can be seen from the above review, a wide range of location determination technologies exists, which use different techniques to determine user location. The particular properties of each technology make it a suitable choice for a specific case. At the same time, such a variation of location determination technologies and lack of standardisation and resulting high costs is also one reason which has hindered their wider application in the construction industry.

Location tracking technologies are often classified as outdoor (i.e. location tracking in outdoor environments) and indoor (i.e. location tracking in indoor environments). In recent years, many construction researchers have demonstrated the potential of using out-door location tracking technologies (such as Global Positioning Systems) to support construction operations (e.g. Meissner et al, 2001; Sacks et al, 2003; Peyret et al, 2000). However, the use of indoor positioning technologies within the construction industry remains limited. Indoor location tracking technologies are important from the viewpoint of this research, as they help in accurate location determination within built environment (also including building structures under construction). Table 7-2 compares various indoor positioning technologies against a set of generic requirements. An example product from each type of technology was chosen, and it was compared against a set of criteria (such as the ability to store data). A three star (***) scoring mechanism is used, where three stars represent a highly appropriate technology while a single star represents a lack of appropriateness of a particular technology. It is recognised that giving such points is subjective to a certain extent, since the alternative technologies, from different vendors, can satisfy the criteria in different ways. Table 3-3 evaluates the appropriateness of using various indoor positioning technologies for typical tracking scenarios for construction site processes.

The comparison between various location-based services (as presented in Table 3-2 & 3-3) was subsequently used to determine the most appropriate positioning technology for prototype development. In the final analysis, a WLAN based positioning technology was used in the prototype development (for the reasons explained in Section 7.6).

Table 3-2: A comparison of various indoor positioning technologies

Positioning Technology	RFID-Based Positioning	WLAN-Based Positioning	Bluetooth-Based Positioning	Dedicated Spectrum Based Positioning
Example Products	www.cotag.com	www.ekahau.com	www.bluetags.com	www.wherenet.com
Description	Includes RFID-based active or passive tags, activated by proximity to a reader. The location of the moving tag is deducted from the location of the reader.	WLAN network tracks WLAN tags/equipment. It measures the signal strength data, which is then correlated with location.	Works on the same principle as WLAN-based positioning, but using Bluetooth technology. Tracks Bluetooth tags/equipment.	Essentially works on the same principle as WLAN and Bluetooth-based positioning. However, it uses a dedicated protocol, to minimise power consumption.
Tag Size	Varied form factor. (Smallest tag is 1x0.5x0.25 inches)	Size of a matchbox.	Size of a matchbox	Size of a matchbox
Battery Life	Either passive (no battery) or active (with battery life of up to 7 years).	Relatively high power consumption, thus low battery life (up to 6 months)	Relatively high power consumption, thus very low battery life (2 weeks lifetime)- Recharging takes 3-4 hours	Uses various techniques to prolong battery life to one year
Proprietary Hardware Required?	Yes, RFID-based positioning requires dedicated infrastructure and proprietary hardware.	No, WLAN based positioning does not require any proprietary hardware. Off the shelf WLAN products (e.g. PDA, Notebooks, Tags, Access Points) can be used for position determination.	No, Off-the-shelf Bluetooth products (equipment/access points) can be used for position determination.	Yes, as it uses a dedicated spectrum, proprietary hardware is required.
Accuracy	Very Poor- Depends on sensing of tags by the readers. (e.g. If readers are 20 m apart, it will result in 20 metre error margin). Also, read time is slow (5.8 milliseconds for each bit), which increases the error margin.	Up to 1 metre, provided three or more access points are provided.	Up to 1 metre, provided there are a number of access points available in the vicinity.	Very high accuracy, up to 0.3 metres

Positioning Technology	RFID-Based Positioning		WLAN-Based Positioning		Bluetooth-Based Positioning		Dedicated Spectrum Based Positioning	
Ability to send and receive data from the tag	Poor – RFID based system primarily supports one way communication i.e. from tag to infrastructure	*	Supports 2 way data e.g. from PDA to infrastructure and vice versa	***	Supports 2 way data e.g. from PDA to infrastructure and vice versa	***	Does not support data transfer to Tag	*
Ability to integrate with existing construction infrastructure¹	Minimal support for integration with existing construction applications	*	High, provides interface to see position of tag on the map and a Java-Based API, to extract position information for use in other applications. Also, it is compatible with GPS.	***	Provides a map for visualising position of tags and interfaces for extracting information	**	Provides API for integration	**
Range	About 12 inches (for passive tags) and 36 inches (for active tags)	*	100 metres	***	50 metres	***	50 -100 metres	***
Tag Costs	About 60 p	***	About £40	*	About £5	**	About £5	**
Infrastructure /installation Costs	Readers required to capture location of tag	**	None (provided accuracy can be achieved through existing WLAN infrastructure). A number of WLAN access points will be required to achieve high accuracy.	***	Access points required, to scan Bluetooth tags. 50 metres range means that compared to WLAN (100 metres range) approximately twice the number of access points will be required. Proprietary software required to scan the tags.	**	Medium costs because of 50-100 metres range. However, cost of access point will be high, because unlike WLAN & Bluetooth, it requires specialised hardware	**

¹ Ability to integrate with the existing infrastructure being used by the construction companies, using an open standards based approach.

Table 3-3: Positioning Technologies Mapping Against Construction Application Scenarios

On-Site Scenario	RFID-Based Positioning	WLAN-Based Positioning	Bluetooth-Based Positioning	Dedicated Spectrum Based Positioning
Tracking expensive assets	No ²	Yes ³	Yes ⁴	Yes
Tracking inventory	Yes ⁵	No ⁶	No	No
Delivering data to users based on their location	No	Yes	Yes	Yes
Embedding information in construction components for later use in project life cycle.	Yes	No ⁷	No	No
Two way communication from tag ⁸	No ⁹	Yes	Yes	Yes

² RFID based positioning works by tracking the location of readers. For accurate location determination, a large number of readers will be required. This will make the cost prohibitive. However, RFID will be a good choice, if only an inventory of assets has to be maintained.

³ Distributed access points can capture the location of equipment using WLAN tags. However, tag size, cost and battery life are a concern.

⁴ Distributed access points can capture the location of equipment using Bluetooth tags. However, tag size, cost and battery life are a concern. In a case study, technology was used to track

⁵ Because of low costs, RFID is well suited for tagging inventory items. However, as location is determined by the location of the reader, margin of error in location may be quite large.

⁶ Costs make it prohibitive to track inventory items.

⁷ Low battery life makes it unsuitable for the purpose.

⁸ Ability of the tags to communicate intelligently with the back end system. For instance, notifying the system, if the tag is stored or located at the wrong place or notifying the system when status of the tag changes. It also include the ability to dynamically store information on the tag.

⁹ Not possible using passive tags. Usage of active tags for dynamic information storage is expensive.

3.4.2. Ubiquitous Computing Technologies

Ubiquitous computing is an emerging paradigm of personal computing, characterised by the shift from the dedicated computing machinery (requiring user's attention e.g. PCs) to pervasive computing capabilities embedded in everyday environments (Weiser, 1991). The vision of the ubiquitous computing require a wide-range of devices, sensors, tags and software components to interoperate. The benefits of ubiquitous computing are perceived as ubiquitous access to information, seamless communications based on wireless technologies and computer mediated interaction with the environment through sensing, actuating and displaying (O'Sullivan et al, 2003). This would provide intelligent support for things people want to do through interpreting their needs and task context. In the recent past several projects have focused on ubiquitous computing. These include IBM's pervasive computing (IBM, 2005), Xerox PARC's ubiquitous computing (PARC, 2005), HP Cooltown (Cooltown, 2005), MIT's Oxygen (Oxygen, 2005) and the EU funded Disappearing Computer (DC, 2005) initiative. Realisation of the vision of the ubiquitous computing has also become possible because of advances in different technologies including microelectronics, low power electronics, memory, sensors, wireless and wired communications, processor architectures, software technologies and communication systems such as mobile phones, Internet and WWW. According to Ailisto et al (2003), the key functionality to implement the ubiquitous computing functionality include:

- Context-awareness (the ability to capture user context such as location and other sensory data);
- Service discovery (finding available service providers in a wireless network);

- Awareness of user requirements/preferences (making the user's desires known to other service providers);
- User-interface design (touch screen, voice input, speech output, etc.);
- The ability to match user requirements to services; and
- Machine learning to improve performance over time, and adapt to better meet the user's needs.

Many of the aforementioned technologies fall within the scope of this research, and are discussed in Chapter 3 and Chapter 4. Relevance of the ubiquitous computing for the construction industry lies in the fact that these technologies have the potential to make construction collaborative processes and services sensitive to the data available in the physical world (Anumba et al,2003a) enabling a wide range of applications from field data collection, to materials management, to site logistics.

3.4.3. Wireless Sensor Networks

The recent advances in wireless sensor networking technology, which have enabled the development of low cost, low power, multifunctional sensor nodes, capable of sensing, data processing, networking with other sensors and data communication to external users (Akyildiz et al, 2002) , promise a much wider range of applications for construction site processes. In the construction industry, sensor networks can be used to monitor a wide range of environments and in a variety of applications, including wireless data acquisition, machine/building monitoring and maintenance, smart buildings and highways, environment monitoring, site security, automated tracking of expensive materials on site, safety management and many others (Aziz et al., 2002) (Figure 3-8).

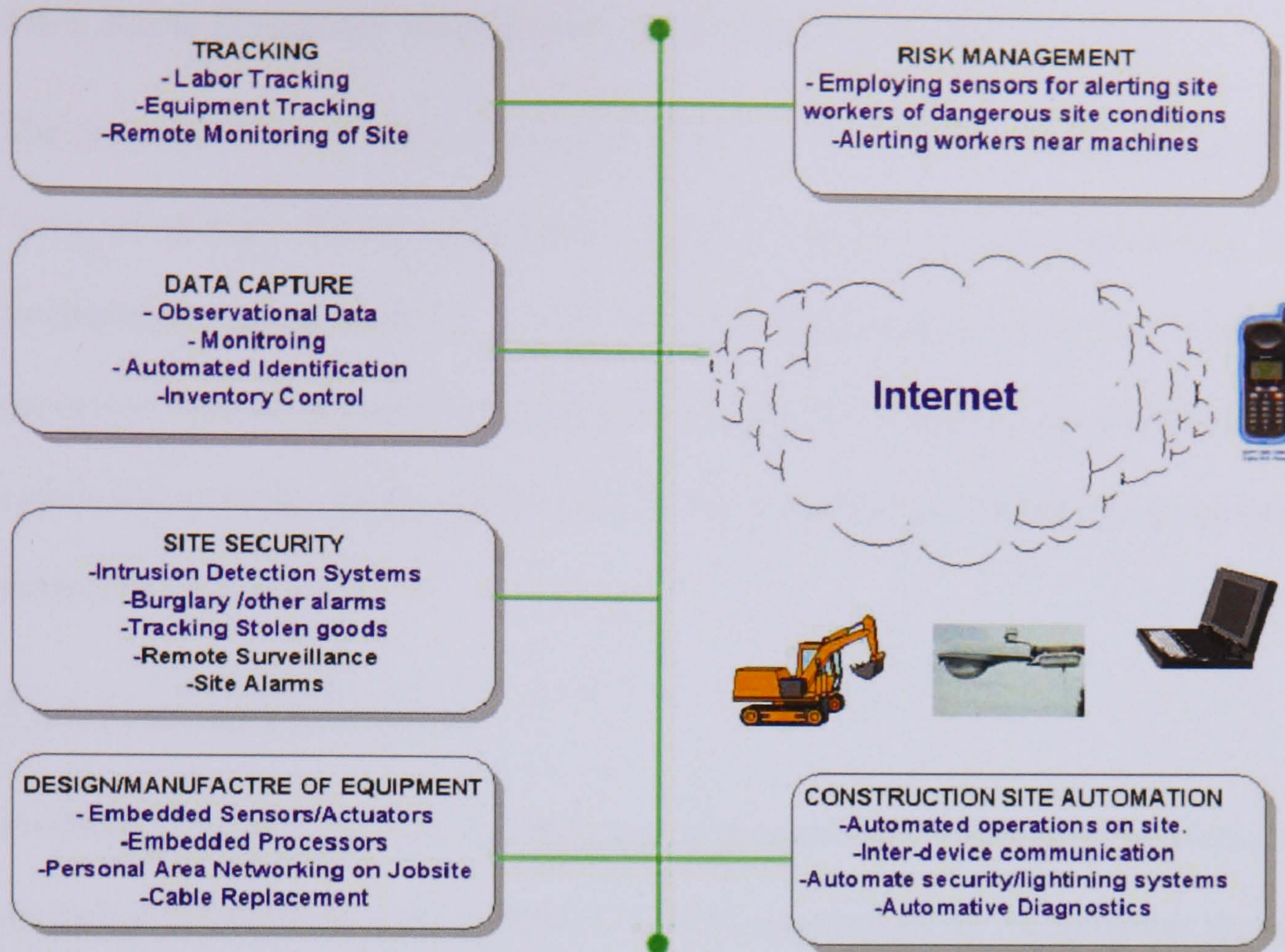


Figure 3-8: Wireless Sensor Networks – Applications in the Construction Industry (Aziz et al,2002)

Sensing intelligence, as enabled by the aforementioned technologies, has the potential to bridge the existing gap between the physical environments of construction workers and the existing virtual collaborative requirements offered by the computer systems. In future, using different hardware technologies such as wireless communications, smart materials, sensors and actuator, it will be possible to add additional context dimensions, allowing for better mapping of the physical and virtual world. It will also allow design of better user interfaces, by shifting the focus from explicit to implicit human computer interaction (Schmidt et al, 1999). It will also prevent users from information overload, thereby allowing mobile workers to do their tasks efficiently and safely.

3.4.4. Radio Frequency Identification (RFID) Technologies

The term RFID describes technologies that use radio waves to identify individual items using tags. Being radio based, it has a non line-of-sight readability. RFID technologies can be used for a wide range of applications to enhance construction processes including materials management, location tracking of tools/equipment, safety and security, supply-chain automation, maintenance and service provisioning, document control etc.

3.4.5. Profiling Technologies

Profiling technologies allow the delivery of personalised information to users, based on their profile and device capabilities. A W3C working group recommends the use of the CC/PP (Composite Capability/Preference Profiles) (CC/PP, 2003) framework to specify how client devices express their capabilities and preferences to the server that originates content. Using the CC/PP framework, information collected from the terminal can be tagged with relevant context parameters (such as location and device-type). It is also possible to enable selection and content generation responses such as triggering alarms or retrieving information relevant to the task at hand. Various commercially available mobile services platform such as Nokia m-Platform (Nokia, 2005) and Ericsson (Ericsson, 2003) provide personalisation support.

3.5. Context-aware Information Delivery Frameworks

In this section, the supporting frameworks which facilitate the implementation of context-aware information delivery are reviewed.

3.5.1. Review of the Existing Frameworks

In recent years, a number of context-aware information delivery frameworks have been proposed. Some of them are reviewed here.

Magdic and Rebolj (2005): This framework focused on supporting communication needs of on-site construction personnel. A key assumption made was that when initiating informal communication, construction personnel already know who to contact. The Presence Server in the proposed framework (Fig 3-9) provides the user with the availability context of a potential contact. The Application Server combines the knowledge of user-presence and user-tasks (by integration with a scheduler application) and on request transfers this combined information via different clients. Knowing information about current status and appointments of the potential contact enables system users to select the timing and media of communication.

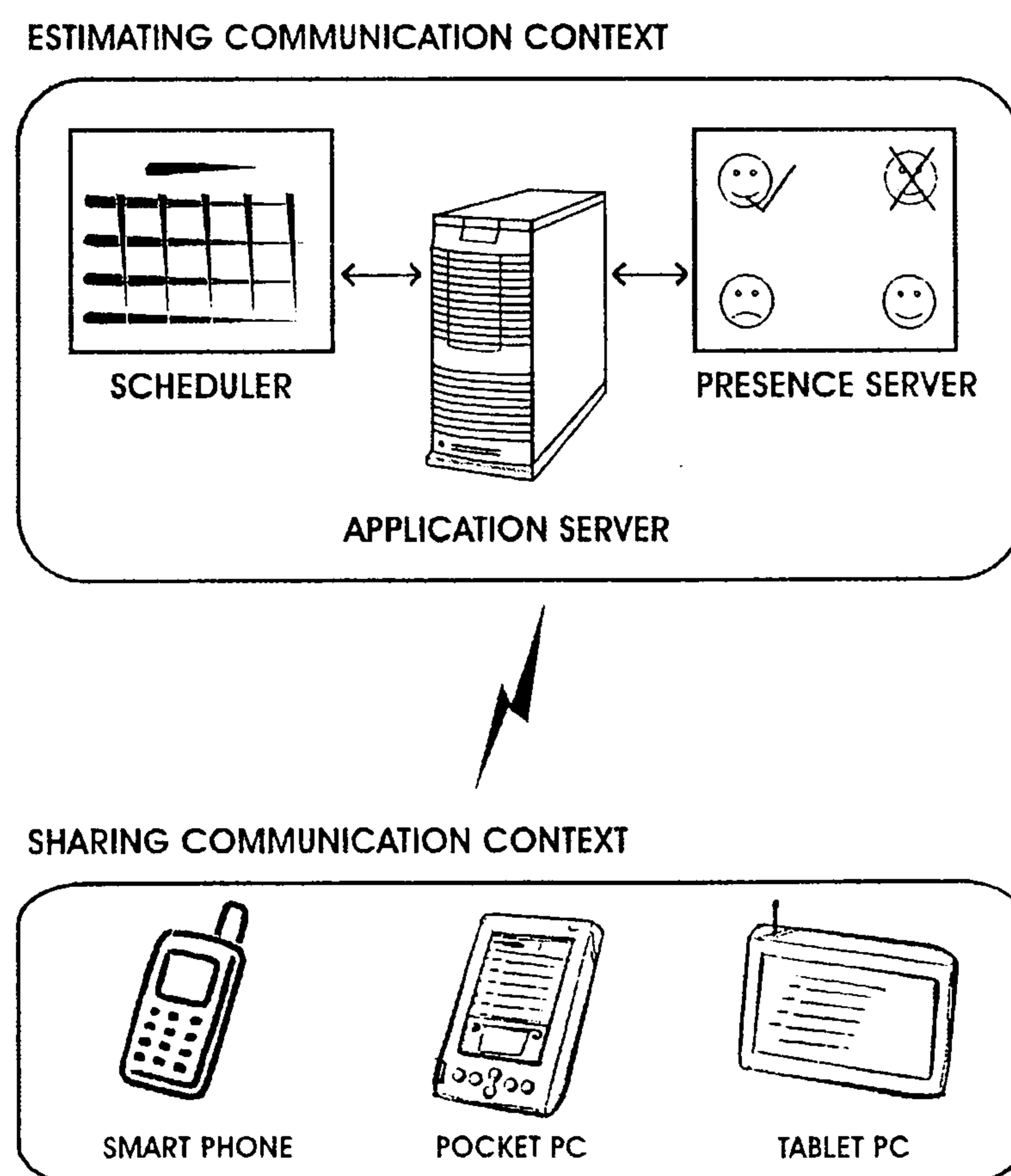


Figure 3-9: Framework proposed by Magdic and Rebolj (2005)

Dey, Salber & Abowd (2001): This approach is concerned with collecting, transforming and delivering context information, with a focus on design reuse. The framework has the following key components:

- **Context Widgets** represent sensor abstractions and provide an interface to automatically deliver information to interested components of the system;
- **Context Aggregators** store multiple pieces of context information (such as a profile or location) that are logically related. These are stored in a common repository for relevant applications;
- **Context Services** control the actuators; and
- **Discoverers** are responsible for maintaining a registry of the capabilities existing within the framework.

Bellotti & Edwards (2001): In this approach, the decision making lies with humans. Based on the captured context, the system presents to the user context information and the actions it is going to take based on the interpreted context. The framework has the following key principles:

- Informing the user of current contextual system capabilities and understandings;
- Providing action-outcome feedback and current and previous action feedback;
- Enforcing action and action disclosure; and
- Providing user control over system and other user actions.

Dourish (2001): Dourish (2001) argued that a context-aware design framework needs to extend beyond mere capture of context parameters, and more towards monitoring of the sociologically motivated explorations of the interaction. This issue is addressed

by investigating the notion of embodiment, which is about establishing meaning and relates to anything that has presence in the world. This includes physical objects, conversations or actions.

Bradley & Dunlop (2004): They developed a multi-disciplinary framework for designing context-aware applications. This framework was based on three principles:

- Acquisition of user context data;
- Acquisition of application context data; and
- Usability design considerations that address the issues arising from the integration of user and application worlds.

Chen et al (2004): Chen et al (2004) developed a semantically-aware framework (Figure 3-10) for different agents to share contextual information and interact according to common understanding regarding these contexts. In this framework, agents model humans, devices and other concepts. Central to this framework is a context broker, which facilitates the interaction between these agents to share contextual information and interact according to common understanding. The context broker acquires context information from devices, agents and sensors in its environment and fuses it into a coherent context model, which is then shared with the devices and their agents.

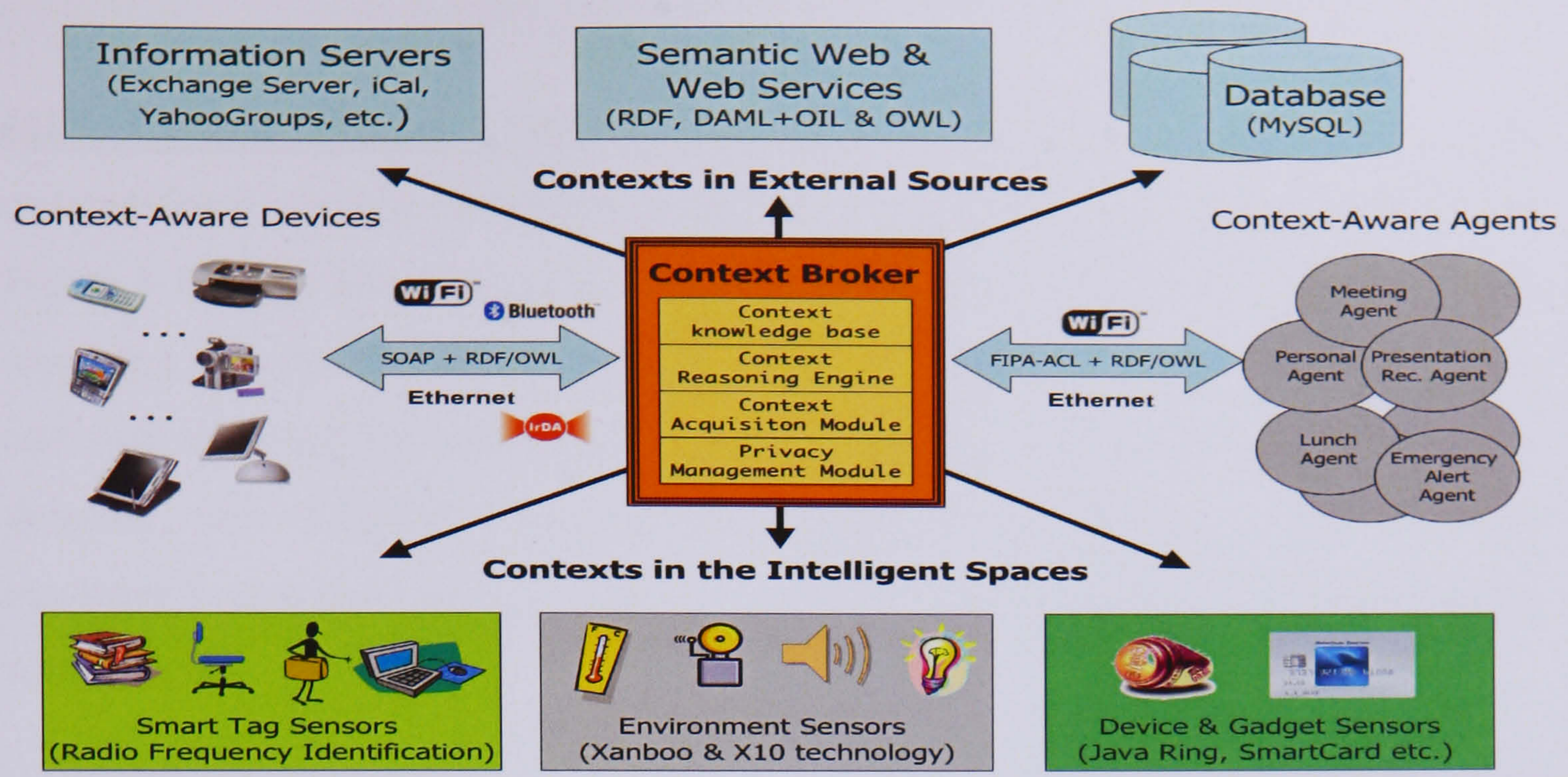


Figure 3-10: Framework presented by Chen & Finn (2004)

Burmakin et al (2002): This framework (Figure 3-11) is composed of a number of components, including a Positioning Service (for providing coordinates of a mobile client inside a building), an Activating Service (for activating different devices that are close to the client), a Mapping Service (for providing context map data to the mobile client according to coordinates), a Registry Service (responsible for keeping references and data about other value-added services) and a Clearing System (responsible for control of access and logging of device (services)).

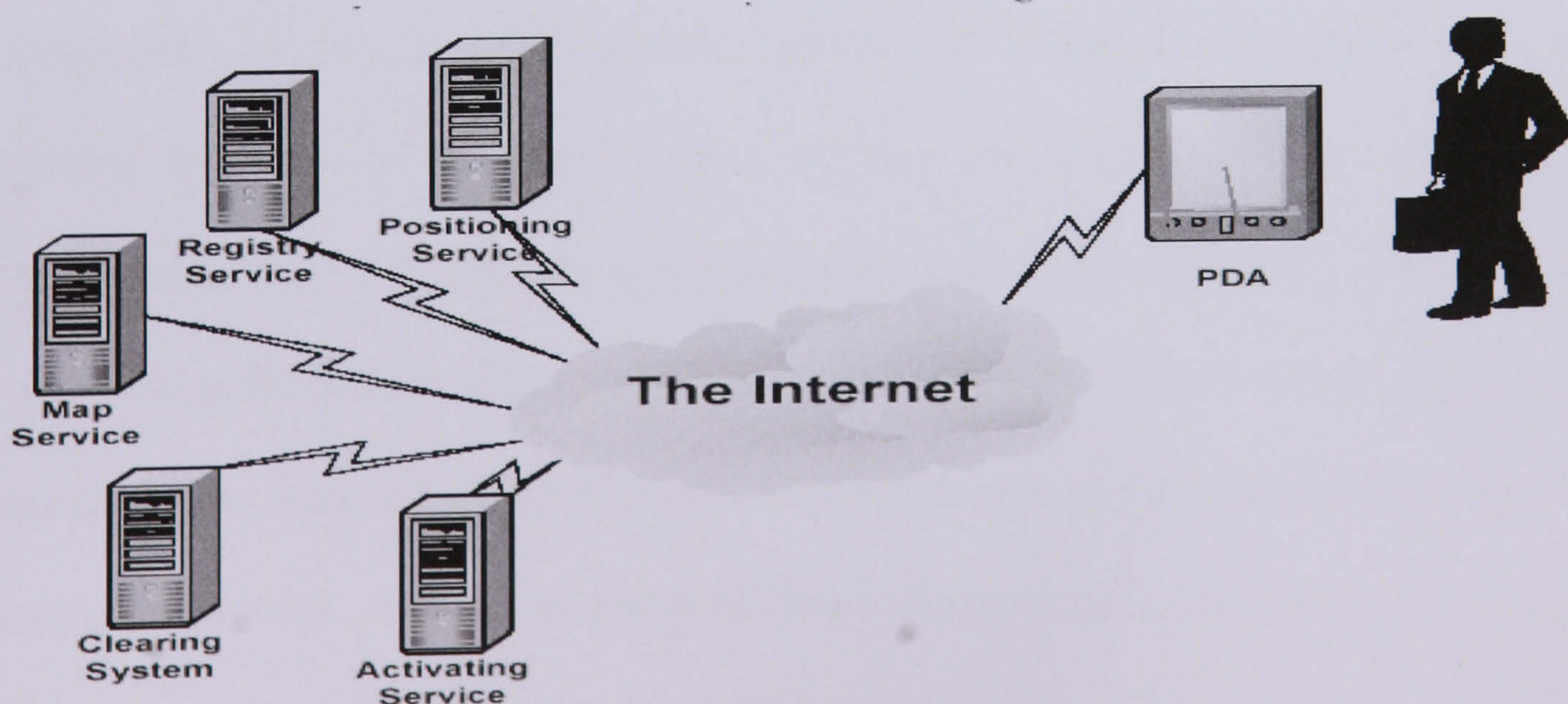


Figure 3-11: Framework presented by Burmakin et al (2002)

MIT Oxygen Project (2005) Approach: This framework is based on the computational devices embedded in the user's surroundings (referred to as E21 in Figure 3-12), that sense and affect a user's immediate environment. User interaction is supported through handheld devices (referred to as H21 in Fig 3-12) with speech, vision and individualised knowledge access and collaboration technologies. It also uses dynamic, self-configuring networks (referred to as N21 in Fig 3-12) which help machines locate each other as well as in locating people, services and resources they want to reach.

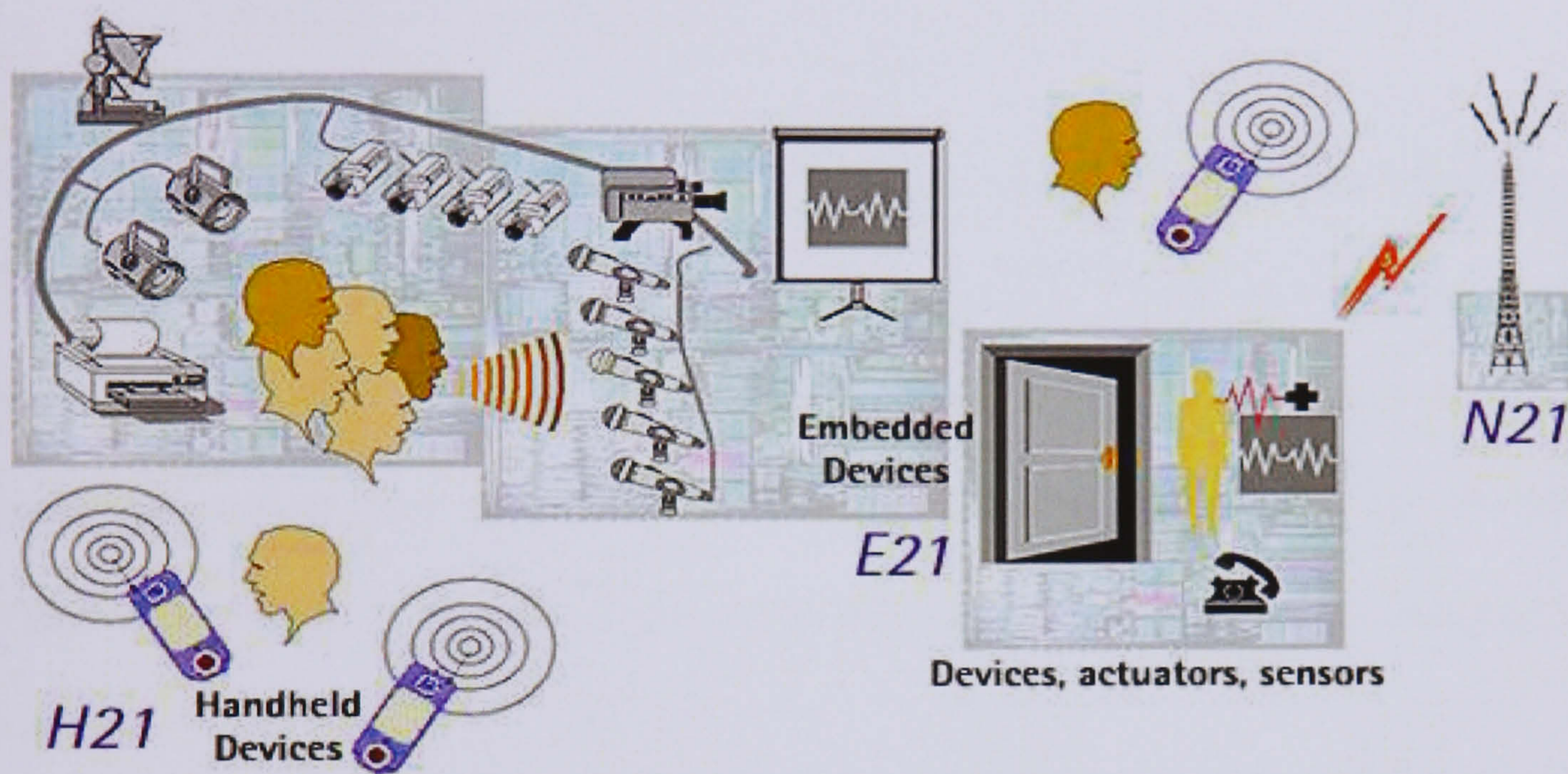


Figure 3-12: MIT Oxygen Framework (Oxygen, 2005)

Sadeh et al (2002): The framework proposed by (Sadeh et al, 2002) revolved around a collection of customisable agents capable of automatically discovering and accessing Intranet and Internet services as they assist their users in carrying out different tasks (Fig 3-13). Every user has a personal environment that controls access to personal preferences and contextual attributes. Contexts information is stored in the context server. Access to resources in a user's personal environment is controlled by permission profiles. A user can allow his/her colleagues to access his or her calendar by allowing their agents to access his or her personal resources.

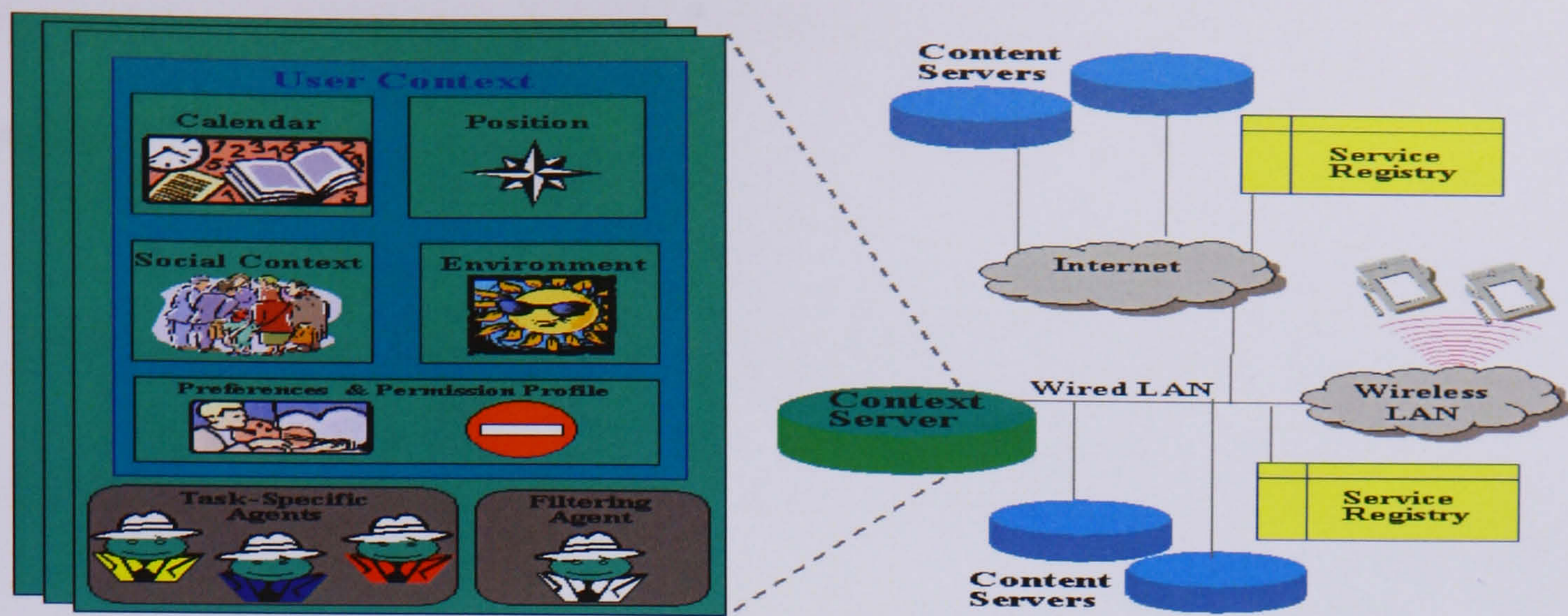


Figure 3-13: Framework proposed by Sadeh et al (2002)

Some of the aforementioned frameworks were predominantly software-oriented (e.g. Dey et al, 2001), while others showed greater appreciation of usability issues (e.g. Bellotti et al, 2001; Bradley et al, 2001). They used different mechanisms for capturing context and reasoning on it. The next section presents the WiSeCon framework, which is tailored to serve the information needs of mobile construction workers.

3.5.2. The WiSeCon Framework

As discussed in Section 3.2.3, the concept of context-aware information delivery, as discussed in this research, centres on the need to provide a pervasive, user-centred mobile work environment for construction workers, which has the ability to provide highly specific data and services by intelligent interpretation of their context (e.g. location, profile, activity, etc). The WiSeCon framework (Figure 3-14) brings together key technology components, to enable creation of a context-aware work environment

for mobile construction workers. The framework is based on multiple tiers, which are explained as below:

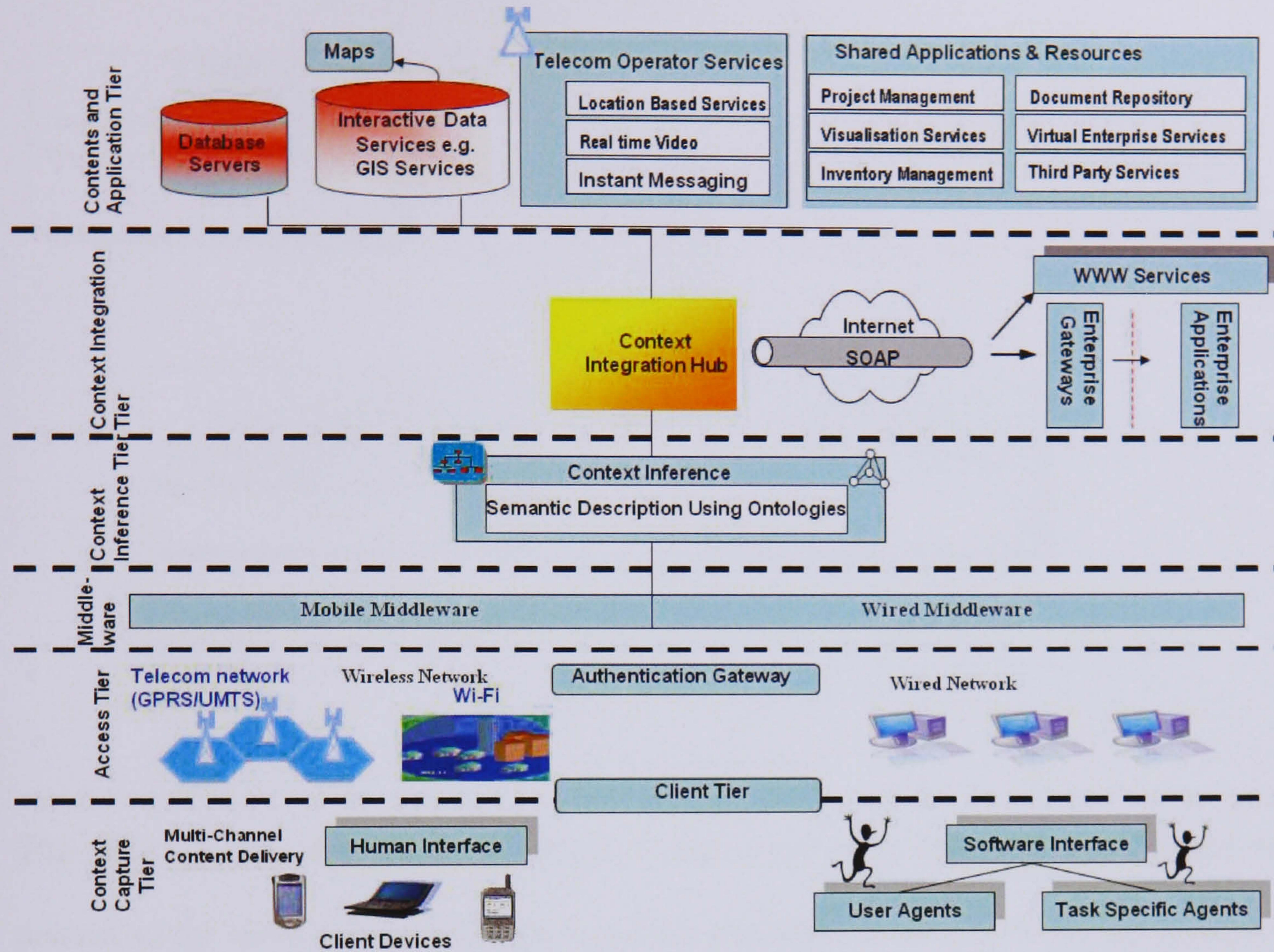


Figure 3-14: The WiSeCon Framework (adapted from Aziz et al, 2004)

3.5.2.1. Context Capture Tier

This tier helps in context capture. It also provides mobile workers with access to the system. In the WiSeCon framework, context is defined as a set of parameters including time, location, user device, user profile and user activity (Figure 3-14). However, it is possible to add additional context parameters.

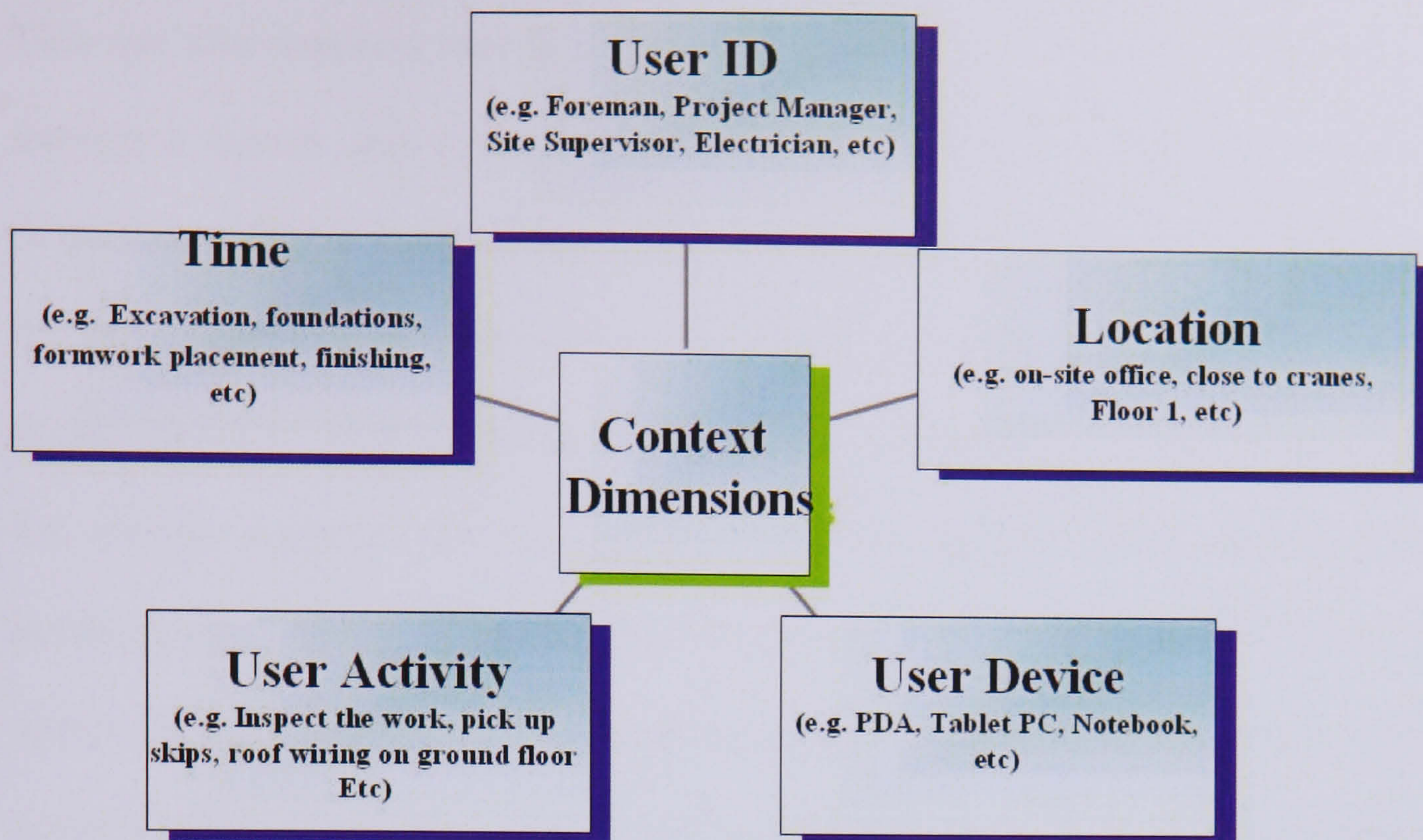


Figure 3-15: Context Dimensions addressed in the WiSeCon Framework

The aforementioned context parameters are used as a filtering mechanism to determine the most relevant information for a particular situation. A mobile worker's context can be captured in the following possible ways:

- User ID, by associating user-preferences with unique IP address of the mobile devices;
- User's current location, via real time tracking of a user-mobile device;
- User device type, via W3C standards, such as CC/PP profiles (CC/PP, 2003).

These standards allow description of capabilities and preferences associated with mobile devices;

- User Activity, through integration with a project management application; and
- Time via a computer clock or through manual input.

This tier also supports mobile workers by providing context-relevant information through a human and a software interface layer. The human interface layer (as described in Figure 3-14) allows intuitive user interaction, by ensuring that data is delivered according to the worker's device type (e.g. Tablet-PC, Pocket-PC, Smart-Phone, etc). The software interface layer ensures integration of software operating on the mobile workers' device with the back-end systems. User Agents allows personalisation of contents and services as per worker's preferences. The task specific agents help mobile workers in accomplishing a specific task by understanding the task context, and by identifying, filtering and accessing the services taking into account the physical conditions on the construction site. As application content, logic and data processing reside on the wired network, the mobile client is charged with minimal memory and processor consuming tasks.

3.5.2.2. Access Tier

The access tier provides the vital communication link between the wired back-end and the wireless front-end. The use of mobile IP-based technologies is envisaged, to enable handover and seamless communication between different wireless communication networks such as wireless wide area networks, local area networks and personal area networks. The access tier supports both push and pull modes of interaction i.e. information can be actively pushed to mobile workers (through user configured triggers), or a worker can pull information through ad-hoc requests, on an as-needed basis.

3.5.2.3. Middleware Tier

An important feature of the proposed architecture is the separation of data from presentation and applications. This separation will allow re-use of the same middle tier for services delivery to wired and wireless clients. Mobile middleware connects desktop based back-end systems with different mobile networks, addressing the limitations imposed by mobility e.g. device limitations, bandwidth variation, etc. Use of XML transformation technologies allow support for a wide range of mobile devices with varying form factors.

3.5.2.4. Context-Inference

The context-Inference tier provides the ability to reason about the captured context. Existing context-aware frameworks use a variety of methods for context-inference. Some of the previously discussed frameworks (e.g. Dey et al, 2001; Dourish, 2001) just enable applications to access the contextual information, but do not provide any other support for context inference. Castro et al (2000) used Bayesian networks to infer context data from sensor data. Chen et al (2003) used the Semantic-Web based context-broker architecture to reason about the context. The approach taken in the WiSeCon framework is influenced by the previous work done by Chen et al (2003). The WiSeCon framework uses the Semantic-Web (explained in Section 4.3) based model to describe a knowledge model for a corresponding context domain, thereby helping context description and knowledge access (by supporting information retrieval, extraction and processing) based on the inferred context. The understanding of semantics (i.e. meanings of data) enable creation of a relationship between the context parameters and available data and services. Based on the changing user context (such as changing user location, user-task or project conditions) list of

relevant data and services are dynamically updated. Output from the context-inference layer can also be fed into construction applications to make them aware of events on the site.

3.5.2.5. Context Integration Tier

This tier will help the construction workers (or their agents) in service discovery. The service hub will use semantic mark-up for resource and service type description. Semantic mark-up will also allow users (or agents) to make intelligent decisions about when and how these resources and services should be used, based on the interpreted context. Adherence to open standards technologies will allow applications to share data and dynamically invoke the capabilities from other applications in a multi-domain, multi-technology, heterogeneous remote collaboration environment.

3.5.2.6. Contents and Applications Tier

This tier contains contain construction project data and applications. Applications may be provided by project partners or application service providers (ASP). Hosting support may be provided by ASP, project participants or wireless network operator, depending on the adopted business model. Using the WiSeCon framework, applications can use the captured context information, in order to provide optimal support for mobile workers. Also, the layered structure of the WiSeCon framework provides an abstraction for application developers i.e. the context data can be used by applications without having to worry about how it was captured.

3.6. Summary

This chapter provided a definition of the concept of context-aware information delivery and reviewed related concepts. It is explained that the “context-aware information delivery” is an ‘umbrella term’, used to define an intelligent work environment for the mobile construction worker which is aware of the user-context. Various context-aware information delivery frameworks were discussed and the WiSeCon framework was presented, to develop an intelligent work environment for mobile construction workers. The WiSeCon framework presents a holistic view of context-aware information delivery, focusing not only on those technologies that can be used to capture user-context, but also addressing those that would help to reason about the context and take subsequent intelligent actions, based on the interpreted context. The next chapter reviews various enabling technologies for context-aware information delivery. Chapter 4 reviews various enabling technologies while Chapter 5 presents various scenarios, explaining the application of the WiSeCon framework in realistic construction situations.

Chapter 4: Enabling Technologies for Context-Aware Information Delivery

4.1. Introduction

This chapter reviews the enabling technologies for context-aware information delivery and explains how these technologies are related to the WiSeCon framework (Section 3.5.2). The last section elaborates on how by exploiting the convergence and synergy between different enabling technologies, it has become possible to deliver intelligent wireless support to mobile construction workers. Technologies reviewed in this chapter include Wireless Communications, the Semantic Web, Web Services and Agent-based Technologies. These technologies are related to the WiSeCon framework in the following ways (Fig 4-1):

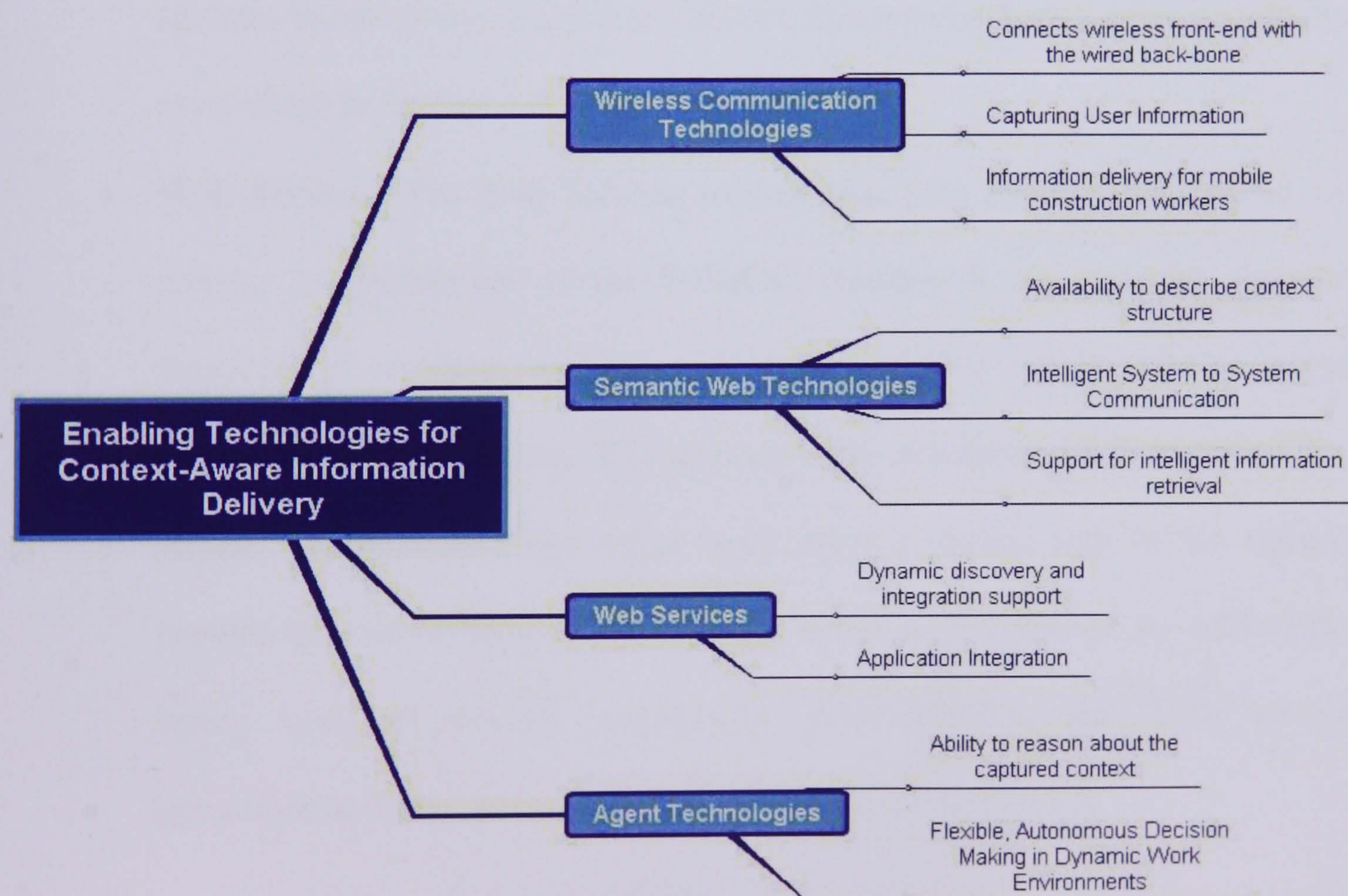


Figure 4-1: Enabling Technologies for Context-Aware Information Delivery

- **Wireless Communication Technologies:** In the WiSeCon framework, these technologies provide a vital communication link between the wired back-bone

infrastructure and the wireless front-end (including mobile devices and tags). Also, they can be used for context-capture (such as user-location via real-time tracking, user identity via IP address of the mobile device) and context-information delivery (using both push and pull mode of interaction). These technologies are explained in more detail in Section 4.2.

- **The Semantic Web Based Technologies:** These technologies play a critical role in the middleware, context-inference and context-integration tier of the WiSeCon framework. In the middleware tier, the Semantic Web technologies allow separation of data from presentation and applications. In the context-inference tier, it helps by providing a knowledge model for the corresponding context domain, while in the context-integration tier, it helps users (or agents) to make intelligent decisions about when and how to use resources and services based on the interpreted context. These technologies are discussed in more detail in Section 4.3.
- **Web-Services:** The Web-Services technologies play an important role in the context integration tier of the WiSeCon framework, by ensuring dynamic discovery of resources and resource integration in a multi-technology and heterogeneous environment. These technologies are discussed in Section 4.4.
- **Agent Technologies:** The Agent layer plays a critical role in the context capture and context inference tiers of the WiSeCon framework, by addressing issues such as security, negotiation, personalisation and Web service procurement. These technologies are discussed in Section 4.5.

All the aforementioned technologies are complementary and work together to deliver context-aware information support for mobile construction workers. They are discussed below:

4.2. Wireless Communication Technologies

The wireless communication technologies can be classified into functionally 4 distinct categories including wireless personal area networking (less than 10 metres range), local area networking (up to 100 metres range), metropolitan area networking (up to 30 kilometres range) and wide area networking technologies (pervasive, usually country-wide coverage). They are described as below.

4.2.1. Wireless Personal Area Networking Technologies

These technologies are meant for short range connectivity, up to a 10 metres range. Bluetooth Wireless technology is emerging as a global standard for wireless personal area networking. Different features of Bluetooth wireless technology and their relevance for the construction-site processes include (Aziz & Tah, 2002):

- Bluetooth supports ad-hoc networking i.e. Whenever any two Bluetooth devices come in a close proximity, the underlying software application establishes connection and can exchange data. This feature particularly suits the dynamic nature of activities on the construction site, where position of nodes can not be pre-engineered, thereby allowing rapid deployment and increased flexibility;
- Bluetooth is lightweight, small sized and has low power consumption requirements (which will suit the rugged environments on the construction site, and will ensure less overheads and maintenance costs);
- It eliminates the need for cabling on the construction site environment and support intra-device communication; and
- It supports both voice and data communications.

4.2.2. Wireless Local Area Networking (LAN) Technologies

These technologies are based on IEEE 802.11x standard and are commonly referred to as WiFi. They are suitable for local area connectivity, up to a 100 metres range. Wireless LAN technology is often used to replace wired LAN or to extend the reach of a wired LAN. The growing acceptance, performance and standardisation of wireless LAN technology is making it affordable. Wireless LAN technology can support construction site-processes in a variety of ways, including provision of wireless access to corporate networks, wireless data acquisition (e.g. Ward et al, 2003), voice over IP support and real-time location-tracking (e.g. Aziz et al, 2005). The key advantage of wireless LAN technologies lies in their low cost and easy availability. However, the security provision of Wireless LAN technology has been criticised in recent years (Olexa, 2005).

4.2.3. Wireless Metropolitan Area Networking Technologies

These technologies are based on IEEE 802.16 standard, and are usually referred to as WiMAX. The key advantages of WiMAX technology include its long range (up to 30 kilometres), high bandwidth (shared data rates of up to 70 Mbps) and its ability to support data-transmission at high speeds (i.e. up to 200 km/hr, suitable for internet access in the trains). With high data-transmission and range, this technology can possibly be used as a backbone technology, connecting on-site wireless LANs with corporate infrastructure.

4.2.4. Wireless Wide Area Networking Technologies

These technologies are appropriate for wide area connectivity such as linking remote construction site operations with design offices. 3G (third-generation) is emerging as a global standard for mobile communications that enables mobile devices to use higher bandwidth (144 to 384 kbps for mobile users and 2Mbps for stationary users). Earlier first generation (analogue based, e.g. GSM) and second generation (digital based, e.g. GPRS) wireless wide area networking technologies were constrained by the amount of bandwidth provided to users and were able to support only voice and text-messaging. 3G technology, in combination with the Internet, is expected to open a wide range of applications in different industry sectors. In the construction industry, 3G technology can be used for remote connectivity to corporate networks (e.g. downloading drawings and data). However, 3G is constrained by its limited bandwidth, compared with other wireless technologies.

4.2.5. Comparison of Different Wireless Communication Technologies

Table 4-1 compares different wireless communication technologies. All of these technologies are complementary, and can be used to serve different connectivity needs of mobile workers. So for instance, for intra-device communication, Bluetooth may be used. To extend a wired LAN or to provide a network coverage on a construction site, WiFi may be employed. WiMAX may be used for wireless connectivity within urban areas, while for collaboration with remote construction sites, 3G is the most appropriate technology.

Table 4-1: Comparison of Wireless Communication Technologies

Parameters	Bluetooth	WiFi	WiMAX	3G
Frequency Band	Varies (typical 2.4 GHz)	2.4 GHz	2-11 GHz	Varies
Range	10 -100 metres (Class 1 bluetooth has 100 metres range)	100 metres	31 Miles	>1000 miles
Data Transfer Rates	Upto 1 Mbps	11-55 Mbps	70-500 Mbps	256 kbps
Number of Users	Dozens	Dozens	Thousands	Thousands
Key Advantages	Low cost, support for ad-hoc networking and intra-device communication	Low cost, easy to deploy, wireless broadband support	Very high bandwidth and high range.	Ability to access Internet (Mobile IP based) and country-wide coverage.
Key Disadvantages	Difficulty in configuring the network, security issues, limited range, limited data transmission	Limited range, security issues	A developing standard, Expensive and market availability is still limited.	Limited bandwidth and expensive (users have to pay per packet of data transferred)

4.2.6. Various Wireless Applications for the Construction Industry

Table 4-2 presents a comprehensive overview of various wireless applications for the construction industry. It also presents advantages/drawbacks of different approaches, possible technology components that can be used for the application realisation, solution components and approximate cost and future trends. The following section presents the relevance of the wireless technologies for the WiSeCon framework.

4.2.7. Relevance of the Wireless Technologies for the WiSeCon Framework:

The state-of-the-art review of the application of wireless/mobile computing technologies in the construction industry was presented in Section 1.4. This section elaborates on the relevance of wireless technologies for the WiSeCon framework. In the WiSeCon framework, wireless technologies provide two key benefits. Firstly, it helps in capturing user context (explained previously in Section 3.4.1 and Section 3.5.2.1). Secondly, it helps in delivering context-relevant information to mobile workers (explained previously in section 3.5.2.1).

Table 4-2 : A Matrix illustrating Potential Applications of Wireless Technologies in the Construction Industry

Application Areas	Application Scenarios ¹	Potential Advantages	Potential Drawbacks	Possible Technologies For On-Site Work	Solution Components and Approximate Costs	Future Trends	Notes
Personal Area Networking (PAN) applications	<ul style="list-style-type: none"> Inter-Device Communication (L) Automated Control of Devices (L) Mobile computing applications (e.g. cell phone linking to laptop) (H) Exchange of position information in piconet (M) Intelligent devices can use Bluetooth wireless components for alerts (L). PAN in wearable Computing 	<ul style="list-style-type: none"> Well suited to pervasive /ubiquitous applications Low power Scalable Self configuring Data Synchronization between devices 	<p>Bluetooth is the key technology for PAN applications. However, it is constrained by its short range (typical range of 10 meters), limited bandwidth (around 720 kbps), difficulty in configuration and support for only eight devices per network.</p>	<ul style="list-style-type: none"> Bluetooth is the key technology for PAN. 	<ul style="list-style-type: none"> Embedding small, low powered radio on chip to traditional electronic devices (£25£+) Associated software with radio chip (this radio and associated software's capable of transmitting and receiving both data and voice communications from other devices) 	<ul style="list-style-type: none"> Ubiquitous Computing characterised by computing spread throughout the environment, mobile users, availability of information appliances, and easier communication between individuals / devices. Smart, Unobtrusive networked devices endowed with sensors, embedded processors, memories, actuators for anytime, anywhere information access Increasing computational abilities due to increasing transistor density on chip and low power consumption Trend in consumer electronics towards embedding micro-processors 	<p>Related Research: Ubiquitous computing applications is being investigated by many research groups as discussed in Section 3.4.2</p>
Wireless Local Area Networking Applications	<ul style="list-style-type: none"> WiFi enabled devices for access to corporate networks and resources (e.g. accessing LAN printers, databases, servers) (H) Using WLAN for voice communications using VoIP (H) Using WLAN for position determination (H) 	<ul style="list-style-type: none"> As above 	<ul style="list-style-type: none"> Security concerns 	<ul style="list-style-type: none"> IEEE 802.11b/a/g standards HomeRF Wireless LAN WiMAX technology 	<ul style="list-style-type: none"> USB adapters or WLAN/Bluetooth Cards (PC/Mobile Phone) (£40 +) Access Points (for radio based connection to wired backbone) (£50 +) Variable, depending on specific application requirements 	<ul style="list-style-type: none"> Shift towards large scale systems, using World Wide Web as a standard platform Increasing low cost connectivity due to wired networks spurred by web and wireless networks for mobile access 	<p>Because of its support for broadband, WLAN technologies provide an ideal platform for developing data intensive construction applications</p>
3G Based Technologies	<ul style="list-style-type: none"> Real-time connectivity for remote construction operations Serving data needs of on-the-move project managers (H) E- Procurement (H) 	<ul style="list-style-type: none"> Simple to use Standardised for Inter-operability 	<ul style="list-style-type: none"> Expensive, as users have to pay a premium to mobile network operator for connectivity Currently, there is a lack of support for application developers who may want to develop their own applications 	<ul style="list-style-type: none"> 3G wireless systems are designed to transmit high-speed data. Implementation of 3G cellular systems will enable successful implementation of Bluetooth Internet Bridge Model. As Bluetooth support both data/voice communication, it is ideally suited for 3G framework i.e. Bluetooth handling local part of connection, while 3G handling global part, providing gateway to 	<p>Solution components and costs will vary depending on the specific application requirements. Typical solution components will include a 3G telecom network and 3G mobile devices.</p>	<ul style="list-style-type: none"> Technologies such as WAP, GSM, UMTS and 3G cellular communication standards resulting in new mobile devices that provide fast and immediate access to Internet. Platform independent mobile code Open standard mobile e-commerce solutions such as Wireless Access Protocols (WAP), Secure Electronic Transactions (SET), European MasterCard / Visa (EMV) protocols. Using non-PC devices e.g. Mobile Phones to access Internet Web Enabled Mobile Phones supporting wireless access protocol (WAP) Using Java for memory constrained embedded devices equipped with Bluetooth 	<p>Prototype 3G applications, with colour video screen for Web Browsing, video conferencing and GPS type positioning are available in the market.</p>

¹ Application scenarios are categorised from the viewpoint of application's potential for construction site processes. H (High Probability) means Bluetooth Solutions that are cheap, cost effective and for which infrastructure does exist. These solutions can be readily adopted at construction site. M (Medium Probability) refers to solutions that are currently not feasible, either because of the lack of infrastructure or because of forbidden costs. These applications cannot be readily adopted, but reduced costs and improved infrastructure may make them feasible in a five years time frame. L (Low Probability) refers to relatively unexplored research areas. These ideas are still in evolution and there adoption is not feasible in next five years.

Application Areas	Application Scenarios	Potential Advantages	Potential Drawbacks	Possible Technologies For On-Site Work	Solution Components and Approximate Costs	Future Trends	Notes
Wireless Data/ Voice Communications	<ul style="list-style-type: none"> Hands free Voice Communications (H) Data communications (H) Remote wireless Email, Internet, Intranet connectivity (H) Electronic Data Interchange applications (H) Electronic procurement (H) Increased collaboration (H) Job Site Record Keeping (H) Cable Free Printing (H) Pen and Paper applications (H) Infra-red replacement using Bluetooth (thus, better range and no line-of-sight requirements) (H) 	<ul style="list-style-type: none"> Increased collaboration Data synchronisation Real-time connectivity /Access to Internet based services Ad hoc networking Wireless connectivity between computing and mobile devices / other consumer electronics Simultaneous support for voice and data using one device 	<ul style="list-style-type: none"> Technology costs and complexity Limited Range of technologies like WiFi / Bluetooth Limited data transmission of technologies like GPRS, 3G, Bluetooth Wireless Interference 	<ul style="list-style-type: none"> Because of broadband support and easy availability, WLAN is the recommended technology for wireless information delivery for on-site operations. However, other technologies can be used to serve complementary needs. 	<ul style="list-style-type: none"> Solution components may vary depending on the choice of technology. A typical WLAN based solution would involve (USB adapters or PC cards), Access points (radio-antenna based connection to the wired back-end) Deployment costs will vary depending on specific application requirements. However, as a general rule, costs in deploying a wireless LAN are less compared to deploying a wired equivalent. 	<ul style="list-style-type: none"> Using Bluetooth for 3G mobile multi-media communication system optimisation. Further integration of Bluetooth functionality with hardware, until all processor functions and radio hardware reside on a single, integrated circuit Emergence of new Bluetooth hardware platforms with integrated software system components True global roaming and voice and data convergence using 3G technologies Convergence of mobile devices with different capabilities such as camera, video devices, voice recorders, smart-phones, tag-readers and PDAs Data synchronisation with current devices suffers from vendor lock in. Trend towards open standards like Bluetooth Platform independent mobile code and use of mobile agents for intelligent wireless communications By 2005, most voice communications and internet access will be wireless Increasing processing power, memories and data storage capabilities (Moore's Law) 	<ul style="list-style-type: none"> Applications in this area are generic, and would primarily be addressed by equipment manufacturers and consumer electronics industry. Some of off-the-shelf products can readily be adopted to serve needs of construction workers. However customisation will allow for better ways to serve information needs.
Location Based Services	<ul style="list-style-type: none"> Real time Location tracking of materials/ equipment/ workforce (M) In-door Positioning (M) Real time location of stolen equipment (M) Provision of location relevant information (M) <p>N.B: There is a wide range of applications for location determination as discussed previously in Section 3.4.1.</p>	<p>This column discusses potential advantages of In-door positioning systems.</p> <ul style="list-style-type: none"> In-Building position determination, typically invisible to satellite positioning systems. More granular positioning opportunities, than possible with GPS Wireless Sensor based positioning (e.g. Exchange of 	<ul style="list-style-type: none"> Limited Range of wireless technologies Key issues in Radio based Positioning still need to be resolved, including need for configuration, maintaining devices right to privacy, quality of service, compatibility with other positioning technologies Limited Battery life 	<p>Generally divided in three categories</p> <ol style="list-style-type: none"> Dead Reckoning (based on concept of direction and distance from starting point) Proximity Systems (Proximity detectors gives indication of moving object) Radio location (Location of mobile object, by measuring radio signals travelling between mobile and base station) 	<ul style="list-style-type: none"> Tags (20€+), embedded with objects for identification Receiver, to locate mobile objects by measuring radio signals travelling between mobile and base stations Antenna collect and transmit the RF signal between the tag and the receiver A Location server, where software processes the event, to determine accurate position. <p>System Cost:</p> <ul style="list-style-type: none"> Identification tags (20€ +)/unit Number of interrogators to 	<ul style="list-style-type: none"> Using Bluetooth/WLAN for position determination for indoor environments for (a) devices with no other positioning capability e.g. laptops, (b) and for devices with GPS or cellular positioning capability e.g. cell phones to improve performance indoors and in built-up environments Defining protocols and procedures that will be used by Bluetooth/WLAN devices implementing position determination, especially in indoor environments. Providing GPS like accuracy indoors Trends towards location awareness e.g. Picking up local contextual 	<p>Related Research</p> <ul style="list-style-type: none"> Location methods have been active field of study over past decade for the purpose of vehicle monitoring, determination of cell service area, and cell traffic area in mobile cellular area. Positioning using Bluetooth/WLAN is currently being investigated by many research groups <p>Commercial Availability</p> <ul style="list-style-type: none"> Bluetooth/WLAN devices

Application Areas	Application Scenarios	Potential Advantages	Potential Drawbacks	Possible Technologies For On-Site Work	Solution Components and Approximate Costs	Future Trends	Notes
		<ul style="list-style-type: none"> position information in a Bluetooth Piconet i.e. Devices at unknown positions can estimate their position by proximity to devices with known positions). Position determination of equipment on site 		<ul style="list-style-type: none"> Commercially available solutions include: <ul style="list-style-type: none"> Real Time Locating Systems (RLTS) Global Positioning System (GPS) Laser Based systems 3D-Real Time Position measurement Transponder Triangulation Technology Inertial Navigation Systems Telecom network based positioning (using cell towers) 	<ul style="list-style-type: none"> detect presence and location of objects (cost: varies from application to application) Bluetooth transceivers (20£+)/unit Software and hardware costs (variable) Implementation and training costs (variable) 	<ul style="list-style-type: none"> information, Picking up local URLs, Time Synchronization Using low cost transceivers for in-building tracking and linking them with GPS. Using GPS and Mobile Positioning Systems for positioning outdoors, and Bluetooth for indoor positioning. Combining GPS, Bluetooth and Cellular Positioning. 	<ul style="list-style-type: none"> with built in GPS receivers to provide positioning information are available commercially. Bluetooth/WLAN tags for location determination are available commercially <p>Note: Competing Wireless Positioning technologies primarily involve trade off between range and accuracy</p>
Visual Monitoring Applications	<ul style="list-style-type: none"> Remote visual monitoring of construction site via web cams/ video cameras (H) Using Web Cams for live transmission of images using mobile phone as a modem (H) 	<ul style="list-style-type: none"> Safer work environment environments (no cables to trip over or unplug) Internet Based Remote monitoring of site activities Little infrastructure required 	<ul style="list-style-type: none"> Limited range and data transmission capacity of some wireless technologies (e.g. Bluetooth & WLAN) is insufficient for real time video transmission Low transmission rates Poor quality of image 	<ul style="list-style-type: none"> Embedded web cams/ Video Conferencing facilities in 3G mobile CCTV systems 	<ul style="list-style-type: none"> Remote controlled, wide range web Cams Site office server Secured web site, for secured access by authorized users <p>System Costs: Variable, depending upon application requirements</p>	<ul style="list-style-type: none"> Remote access to 3D visualisation and collaborative visualisation sessions Web based and/or multi-media visualisation support using Java/VRML Terrestrial or satellite based tele-observation In recent years, many construction firms have deployed browser based or web based applications for monitoring, archiving and managing the live images from construction site. 	<p>Commercial Availability:</p> <ul style="list-style-type: none"> Web Cameras and video monitoring solutions for different wireless technologies are available commercially
Wireless Sensor Networks	<ul style="list-style-type: none"> Detection of events on site e.g. Appliance failure, intrusion detection etc.(M) Data Capture Applications (M) Tracking equipment/labourers on site(M). Personal Area Networking on site (M) 	<ul style="list-style-type: none"> Flexibility Collaboration of sensor nodes, to form personal area networks Rapid Deployment Fault tolerance Interaction with internet 	<ul style="list-style-type: none"> Interoperability issues High cost Power consumption issues Protocol requirements 	<ul style="list-style-type: none"> Different wireless sensors are being used for wireless sensor networking, depending upon the application requirements. 	<p>Solution Components:</p> <ul style="list-style-type: none"> Integrating sensors with radio technologies (e.g. Bluetooth chip) to make wireless sensors Distributing sensors over construction site etc as per application requirements Sensors will organise themselves into piconets and scatternets These piconets and scatternets can then be linked with Local Area Networks, or with GIS for real time geographic and virtual reality display 	<ul style="list-style-type: none"> Recent advances in wireless communications, micro-electro-mechanical systems (MEMS) have made the concept of wireless sensor networking affordable 	<ul style="list-style-type: none"> Potential of using wireless sensor networking for construction site processes was investigated by Aziz et al (2003). Commercially available wireless sensor networking solutions are expensive (5000\$ + price tag)
Automated Identification and Data Capture (AIDC) Applications	<ul style="list-style-type: none"> Tracking and Traceability of items Material/Asset Management (M) Proof of Delivery Services (M) Supply chain automation (M) Just-In-Time Managed 	<p>Various advantages of active tags are discussed:</p> <ul style="list-style-type: none"> Ability to store data Non-line of sight Small, low power, low cost transceivers Tag's reusability-Read/Write ability Suitable for rugged 	<ul style="list-style-type: none"> Limited range of RFID technologies (<10 m) Radio wave inference Readers required at every data collection point, resulting in a relatively high expensive cost of the total solution 	<p>Interfaces</p> <p>Based on the radio frequency, there can be different technology interfaces</p> <ul style="list-style-type: none"> Low Frequency (100-500KHz) RFID technologies Medium Frequency 	<p>Typically these applications include a tag, a reader and an antenna.</p> <ul style="list-style-type: none"> RF Tags (20£+)- These are small low power microchip combined with an antenna, implanted in a physical object and programmed with information or chip powered by tags inductively powered by tag 	<ul style="list-style-type: none"> Project information databases, linking RFID/Sensors data captured on site with key project information like part ID, CAD/VRML, 3D models, links to suppliers data, and positioning information Embedded Internet Systems (RFID/electronic identification, with processing power connected to 	<p>Related Research:</p> <ul style="list-style-type: none"> AIDC applications have been a focus of many research efforts for past many years. Most of the research on AIDC applications for construction industry has been conceptual in nature. <p>Commercial Availability:</p>

Application Areas	Application Scenarios	Potential Advantages	Potential Drawbacks	Possible Technologies For On-Site Work	Solution Components and Approximate Costs	Future Trends	Notes
	<p>Inventory Systems (M)</p> <ul style="list-style-type: none"> Auto-Tracking Labourers/ Materials on site (M) Hazardous materials handling (M) Identifying Stolen Equipment (M) Enable rotation (e.g. using cement bags in circulation) <p>Authentication</p> <ul style="list-style-type: none"> RFID keys (H) Access Control (M) Time/ attendance control (M) Automated Personalization of multi-user devices, for context sensitive information provision e.g. entry without physical keys (L) <p>Data Capture</p> <ul style="list-style-type: none"> Field Data Collection (M) Structural Assessment (M) Building / Facilities Maintenance (M) Equipment Maintenance (M) 	<p>environments</p> <ul style="list-style-type: none"> 30-foot read distance Open Standards RFID systems does not require human intervention Automation Support (e.g. Proof of delivery service etc) Low Power Consumption (1 Milli-Watt) Ease of Usage Cable Replacement e.g. Building intelligent buildings without costly built in cabling. Omni-directional Other advantages which characterize typical RFID systems such as Simultaneous reads etc. 	<ul style="list-style-type: none"> Lack of construction industry specific applications Security Concerns (Pin keys, device addresses and encryption keys can easily be hacked by electronic bugging devices) Power consumption problems of active tags Limited data transmission rates 	<p>(500 KHz-850 MHz)</p> <p>RFID Technologies</p> <ul style="list-style-type: none"> High Frequency (850MHz-5.8 GHz) <p>RFID Technologies</p> <p>Tags</p> <ul style="list-style-type: none"> Barcodes Smart cards Smart Labels Ibuttons Magnetic strips Biometrics Magnetic Ink / Optical Character Recognition Java Ring Optical mark reading <p>Other Technologies</p> <ul style="list-style-type: none"> Speech Recognition Systems Electronic writing pads Vision recognition Digital Image Capture Systems 	<p>interrogator through magnetic induction and tag responding with ID through a modulated carrier</p> <ul style="list-style-type: none"> RFID readers that send and receive messages using Bluetooth's 2.4GHz frequency Antenna collect and transmit the RF signal between the tag and the receiver A server with database and application software that associates tag with particular resources. <p>System Cost:</p> <ul style="list-style-type: none"> Programmable tags (20£ +)/unit Readers (5000£+): Readers would probably be most expensive items, costing £1,000-£4,000. Radio transceivers (20£+)/unit Software and hardware costs (variable) Implementation and training costs (variable) 	<p>Internet)</p> <ul style="list-style-type: none"> Smart Card Applications Electronic identification for context sensitive information provision / personalisation of electronic devices Trends towards open standards to bridge the islands of automation Transmitting RFID captured data in real time via GSM networks to corporate LAN. Web based information retrieval/ data analysis Making everyday objects smart, by attaching RFID labels to them and by equipping environment with sensors/readers for those labels. These electronic identities with than interact with the virtual world, independent of the physical world. 	<ul style="list-style-type: none"> Prevalence of a wide range of AIDC technology and standards is proving to be a barrier in wider adoption. While considering application of Bluetooth Wireless technology for AIDC applications, it should be noted that choice of radio frequency for AIDC applications to a large extent would depend on application requirements and intended usage model. <p>Note:</p> <ul style="list-style-type: none"> Most applications get M grade primarily because AIDC applications are yet not widely adapted by the construction industry

In the past, problems that have limited the widespread adoption of mobile computing technologies in the construction industry included the narrow bandwidth of wireless technologies, difficulties in configuring the wireless network, costs, the limited processing power and the memory capacity of the mobile devices that would allow users to run useful applications /application clients on the mobile devices (Anumba et al, 2003). With the emergence of high speed wireless networks, such as Wi-Fi, WiMAX and 3G, it has become possible to efficiently extend desktop based construction applications to mobile and wireless devices. All the wireless technologies discussed in this section (i.e. Bluetooth, WiFi, WiMAX, 3G) are based on IP, which enable the convergence of voice, Internet and construction data. Coupled with an ability to utilise user-context information, will create significantly new opportunities for enhanced collaboration between construction project team members by enabling new application scenarios such as personalised information delivery based on user location and task at hand etc.

4.3. The Semantic Web

The Semantic Web is an extension of the current World Wide Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation (Bernerslee et al, 2001). It allows the data to be defined and linked in a way that it can be used by machines not just for display purposes but also for automation, integration and data reuse. This way it enables access to Web resources by contents rather than just by keywords (Ankolekar et al, 2001). The Semantic Web technologies provide intelligent access to heterogeneous distributed information, enabling software applications to mediate between user needs and

information sources (Fensel, 2001). Figure 4-2 illustrates the layers of the Semantic Web Architecture as defined by W3C (W3C, 2005), which are described below:

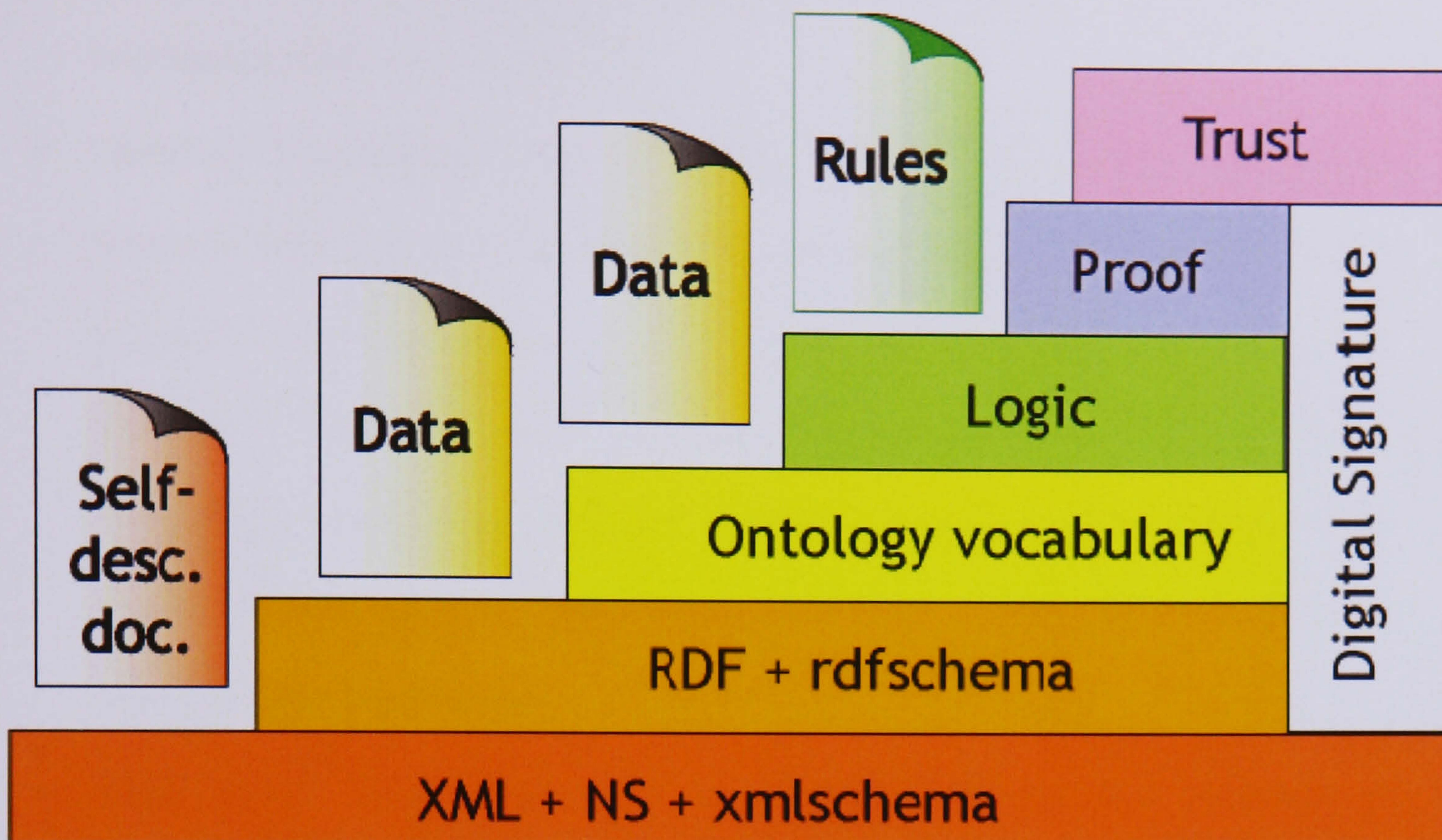


Figure 4-2: Semantic Web Technologies (W3C, 2005)

- **XML + NS + XMLschema layer:** XML provides the common syntax, while Namespace (NS) and XML Schema define contents and rules;
- **RDF and RDF Schema Layer:** RDF (RDF, 2005) is a conceptual data layer which builds on XML. It is application and domain neutral, and defines a metadata layer and domain specific vocabulary. RDF model can be used to describe anything that has a Universal Resource Indicator (URI). Resource Description Format (RDF) uses the namespace mechanism to make sure each name is unique. The main goal of RDF is to enable the automation of many Web-related activities, such as resource discovery (Alesso et al, 2001). It also defines mechanism for describing resources that makes no assumptions about a particular application domain, nor defines the semantics of any application. Such models are

used to address reuse and components (software engineering), to handle problems of schema evolution (database) and for knowledge representation (Artificial Intelligence) (Alesso et al, 2001);

- **Ontology Vocabulary Layer:** This layer is the backbone technology for the Semantic Web. It provides a common language on the human and machine level to enable knowledge exchange. An ontology provides semantics of data and information sources that can be communicated between different agents (Fensel, 2001), thereby facilitating knowledge sharing and reuse at a human-to-machine or machine-to-machine level. Web Ontology Language (OWL, 2001) is used as an ontology definition language.
- **Logic layer:** This defines rules for dynamic inference and definition of hierarchies and processing of schemas and instances; and
- **Proof and trust layers:** They involve rating of sources and processes and monitoring of logical steps.

From the view point of applications in the construction industry, the Semantic Web technologies offer considerable benefits in terms of project management, content and document management, knowledge management, supply chain management and integration of distributed applications and services (Anumba et al, 2003). This section explains how the Semantic Web technologies relate to the WiSeCon framework:

4.3.1. Understanding of the Document Semantics

The Semantic Web technologies (such as ontologies) can help in the deeper understanding of the semantics of the construction documents and project task structure (Aziz et al, 2004). Combined with the increased awareness of the worker's

context (as enabled by the WiSeCon framework), this would help in intelligent information retrieval, extraction and delivery of context-relevant support for mobile construction workers. Fensel (2001) explained how Semantic Web technologies can be used to support task achievement, information access and source finding (Fig 4-3). From the viewpoint of a mobile construction worker, such support is critical to accomplish elements of the project plan.

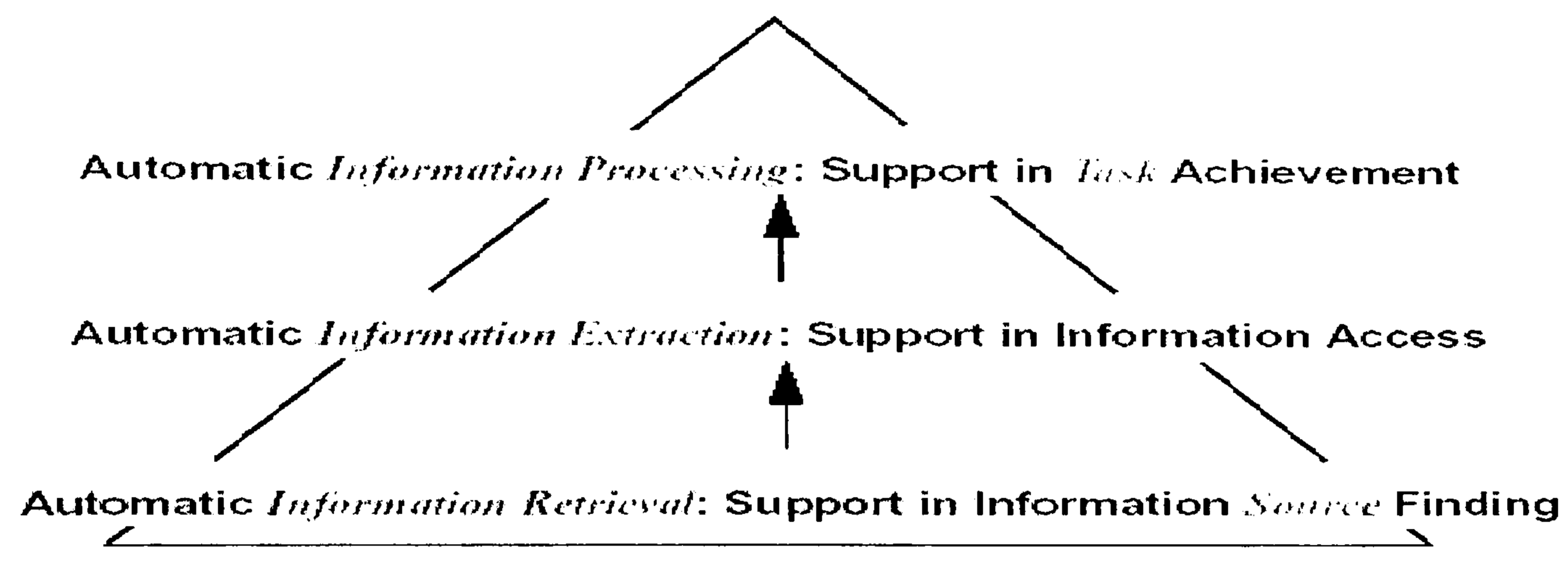


Figure 4-3: Layers of the Semantic Web Services (Fensel, 2001)

4.3.2. Separation of presentation from data

In the middleware tier of the WiSeCon framework, the Semantic Web technologies allow separation of data from presentation. This separation allows the reuse of the existing desktop-based ICT infrastructure for service delivery to both wired and wireless users. Also, the Semantic Web technologies are based on XML. XML being text based, can be transformed for presentation on different platforms and devices such as Pocket PC, Smart Phones, Wearable Computers (Fig 4-4).

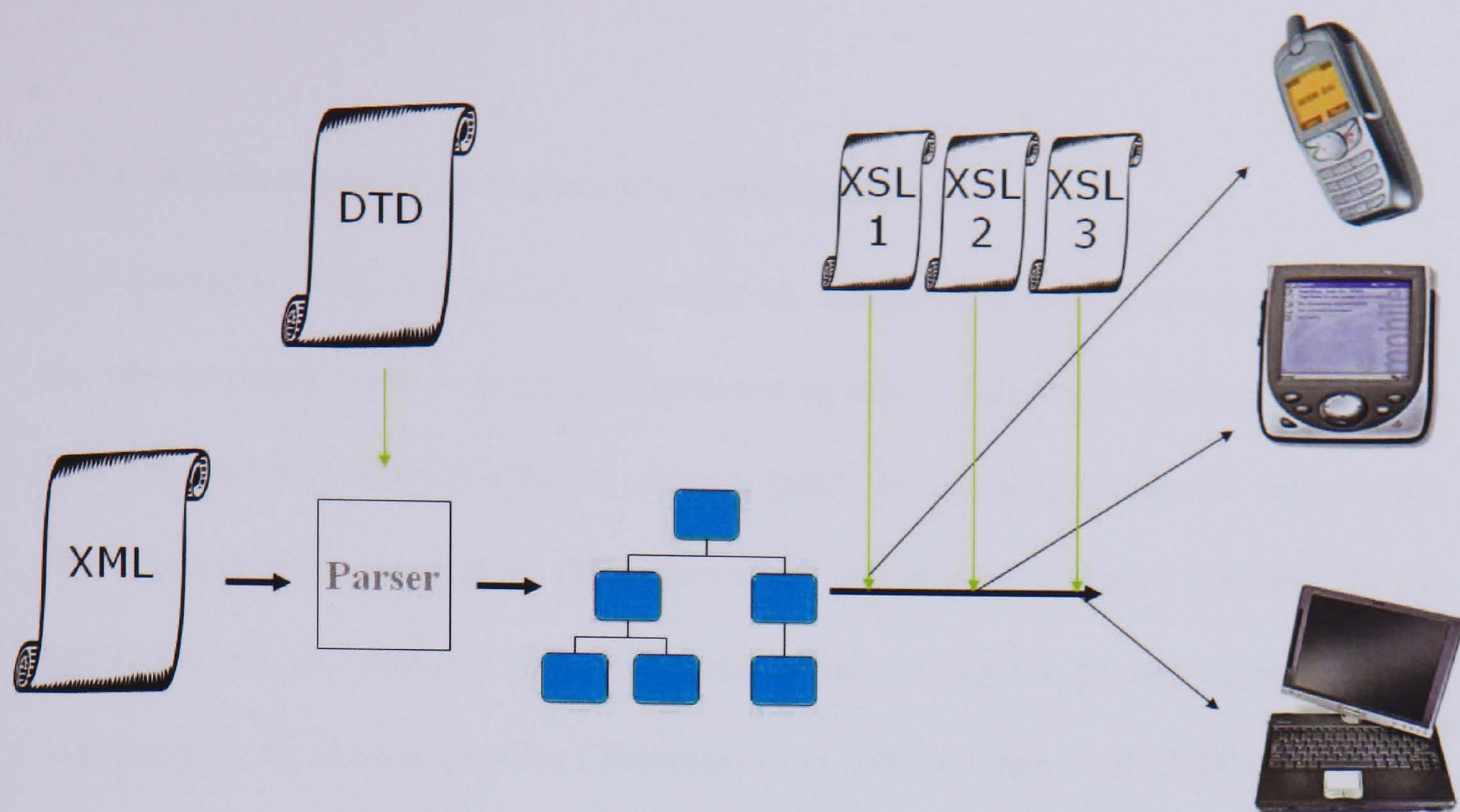


Figure 4-4: Separation of data and presentation (Aziz et al,2003a)

4.3.3. On-the-fly Resource Discovery and Integration

Semantic Web techniques, through the introduction of ontological reasoning, are suitable for flexibly discovering abilities in using information, which was not specifically designed or intended for a particular use case (Lassila et al,2003). Thus, it enables automated agents to reason about the Web content, and produce an intelligent response to unforeseen situations. In the WiSeCon framework, the Semantic Web technologies can be used to describe various services and resources. This would enable the human users (or their software agents) to take intelligent actions based on the interpreted context of the user. For instance, by annotating construction documents with semantic meta-data, agents can readily understand the full context of what a particular resource means and can take decisions about how these resources should be used. Also, as the Semantic Web technologies support machine-to-machine communication, it can be used to automate various tasks.

4.3.4. Standardised Way to Interpret User Context

The Semantic Web technologies provide an independent way to interpret context, thereby enabling both humans and software agents to infer new context knowledge and consequently take intelligent actions (such as extracting relevant information from databases or integrating the information spread over different sources). In the Konti Project, an ontology was developed for expressing the properties required for constructing contextual profiles (Toivonen et al, 2003). Chen et al (2004) applied the Semantic Web technologies for modelling ontologies of context and for supporting context reasoning.

4.3.5. Increased Interoperability

Construction companies very often perform their processes in different ways. Difference in meanings of terms and mode of operation makes collaboration difficult. As demonstrated in the E-Cognos project (Lima et al,2003), the use of shared ontologies and semantic standards will ensure increased interoperability across devices, platforms and applications, thereby significantly contributing towards the goal of construction knowledge management. The Semantic Web-based rules are starting to be applied in large scale distributed systems in the construction industry. Lai et al. (2002) has focused on the application of the Semantic Web technology in early design collaboration for knowledge capture, quality assurance and Web accessibility and support. The E-Construct project (E-Construct, 2005) focused on the application of the Semantic Web technologies to the transfer and sharing of knowledge across ICT systems. It also defined a common communication-oriented language, called bcXML, aimed at facilitating e-commerce transactions. The aecXML

(2003) initiative aims to develop standard XML schemas for different AEC project information including resources (e.g. project documents, materials, parts, etc) and activities (e.g. design, estimating, scheduling, construction, etc). Other than aecXML, there are many other ontology standards such as STEP, ifcXML and PSL (Process Specification Language) that have been proposed for the AEC sector. The different ontology standards provide users with various choices according to their specific needs. However, these different standards may hinder interoperability since different applications may opt to adopt different ontology standards. Cheng et al. (2002) investigated the ontology mapping between different standards for project scheduling applications and Halfawy et al. (2002) reviewed the requirements and a methodology for developing, implementing and standardising an extensible set of common message based protocols for exchanging project-specific and industry wide information based on the IFC data model. The IFC data model was used as a data dictionary that defines the semantics necessary to represent, share and exchange information about AEC projects, products and processes. Although the Semantic Web based rules are starting to be applied in the construction industry, full realisation of the Semantic Web vision is possible only when common standards are evolved and adopted industry-wide (Aziz et al, 2003).

4.3.6. Creation of an Intelligent Construction Site

The Semantic Web technologies also play a major role in the context-capture tier of the WiSeCon framework, by uniquely defining different objects (e.g. construction equipment, materials, components, devices, etc) in the physical world and by enabling service discovery and integration at an intra-device level. Lasilla et al (2003) describe the relationship between the Semantic Web and ubiquitous computing as follows.

“The Semantic Web and Ubiquitous Computing are related insofar as devices in the Ubiquitous Computing world can be regarded as services which can benefit from semantic tagging and matchmaking technology”. In recent years, many researchers have focused on the application of the Semantic Web technologies in the realm of ubiquitous computing (e.g. Lasilla et al, 2003, Sashima et al, 2002; Adler, 2001). Adler (2001) has investigated the convergence of the ubiquitous computing infrastructure and the Semantic Web and described three different ways (represented in Fig 4-5) the Semantic Web technologies can help in the realm of ubiquitous computing, which are explained below:

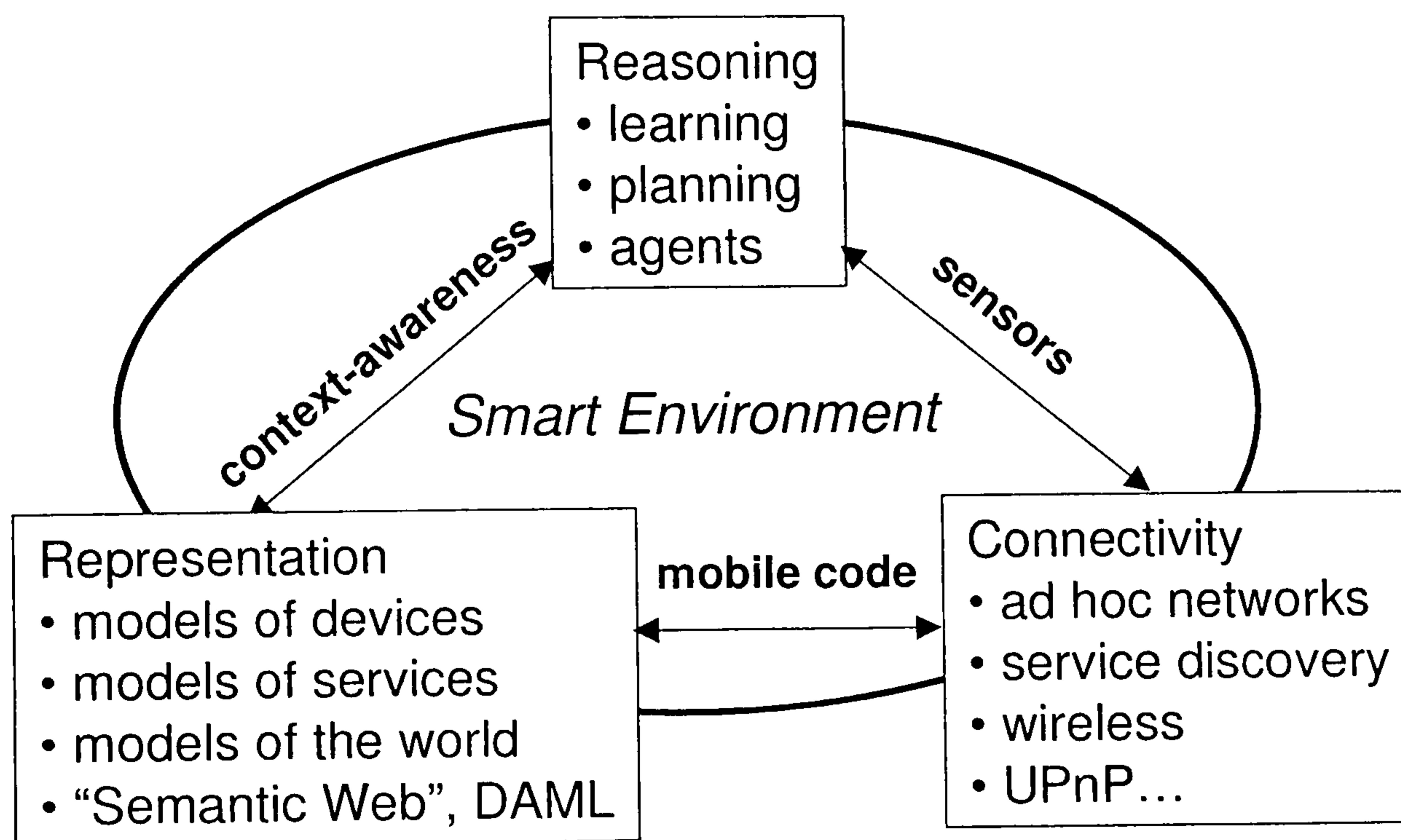


Figure 4-5: Semantic Web and the Ubiquitous Computing

Representation: The Semantic Web enable explicit representation of device capabilities and service functionality, individual addresses for everything URIs and the Semantic Web as the basis for “semantic interoperability”. The Semantic Web enables individual addresses for everything (using URI). URI can point to anything in the physical world, including RFID tags, sensors, cameras, wearable computing devices, etc. Such ubiquitous computing devices can advertise their functionality-

what they can do and how they are controlled- much like software agents. RDF based CC/PP (2003) standard helps in describing functional capabilities of devices and user preferences. By adding languages for handling ontologies and logic, devices could automatically seek out and employ services and other devices for added functionality, enabling automation with minimal human intervention (Berners-Lee et al, 2001). This will enable multi-device capability through the specification of any Web resource. Currently available service discovery and capability description mechanisms include Sun Microsystems's Jini (Service Focused) and Microsoft Universal Plug and Play (device focused). They describe the mechanism through which functions offered by various ubiquitous computing devices are described, advertised and discovered by others. Similar service discovery and capability description mechanisms are explored by Lassila et al (2003), who proposed a framework in which mobile communication devices have the capability to automatically configure themselves in the new environments and to combine information and functionality from local and remote sources.

4.3.7. Task Automation

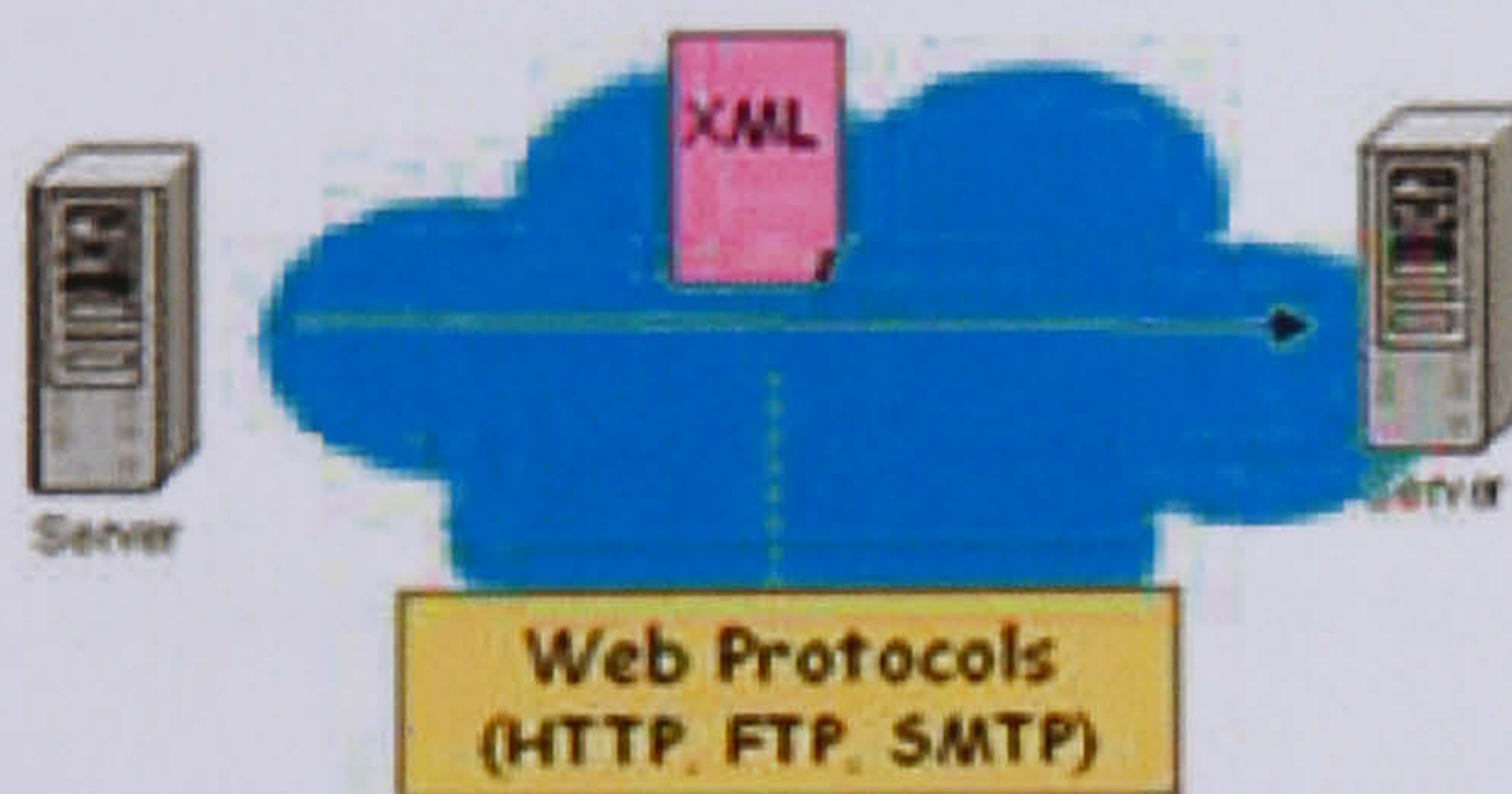
A key idea of the Semantic Web technologies is to delegate many human specific Web activities to computers. To achieve this goal, the Semantic Web technologies describe data in machine readable format using XML based RDF and other technologies, thereby enabling machine to machine communication.

4.4. Web Services

Web Services are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web using standard Internet protocols.

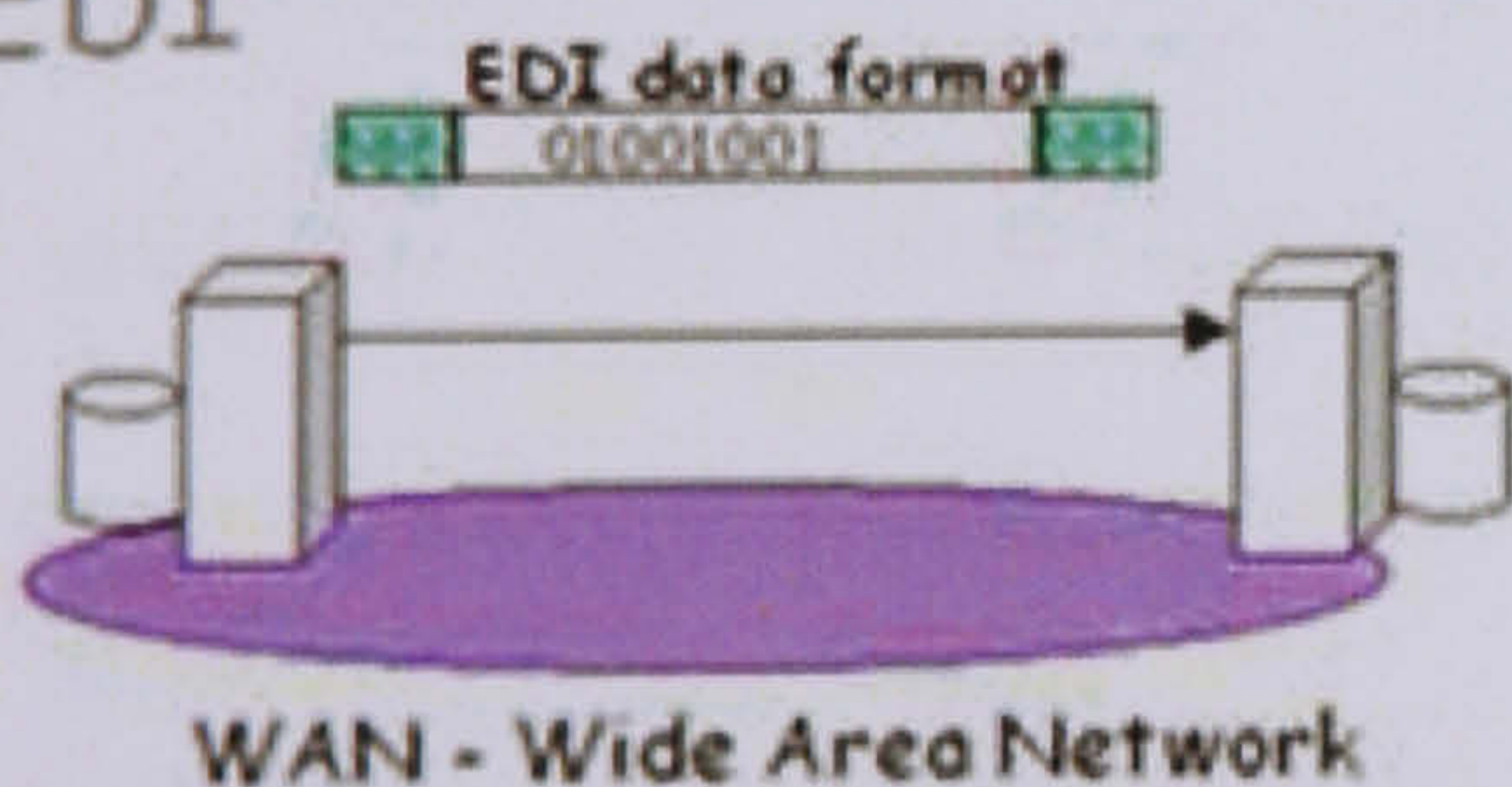
Once a Web Service is deployed, other applications (and other Web Services) can discover and invoke the deployed services regardless of operating system or programming language (Kreger, 2001). As identified by Fensel (2001), the key to Web Services is on-the-fly software creation through the use of loosely coupled, reusable software components. In contrast, previously used systems based on established infrastructures such as CORBA, RMI and EDI were tightly coupled, each with their own transport protocol and inability to communicate with TCP/IP protocol. Using Web Services, data is free to move about the Web without the constraints imposed by tightly coupled transport dependent architectures (Fig 4-5) (Coyle, 2003). Thus, the Web Services technology ensures standards based low cost integration.

Web Services



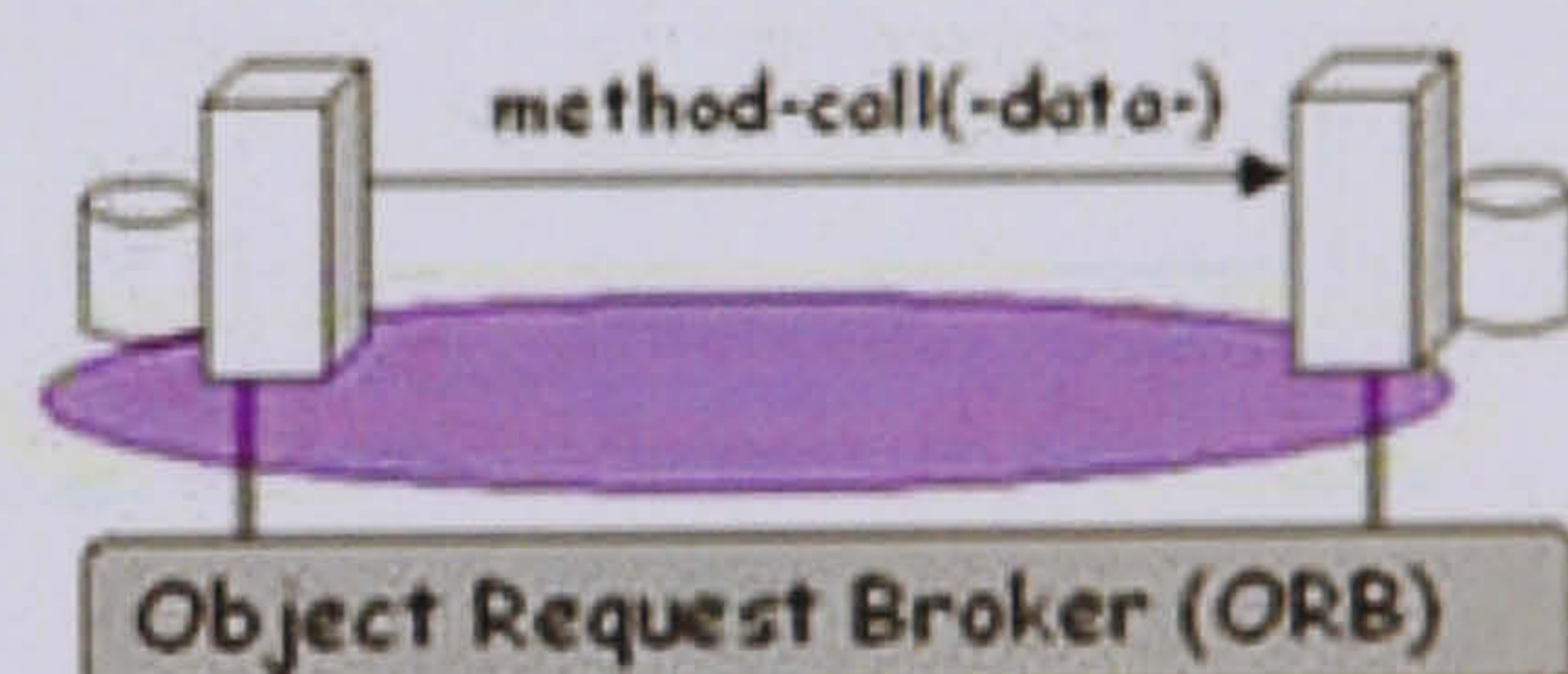
Data is free to move about the Web
- not dependent on programming
language or transport protocol

EDI



- > data formats and messages defined by EDI standards
- > applications run in batch mode outside the internet
- > proprietary wide area network (WAN) required to deliver EDI messages

CORBA, RMI, DCOM



- > data passed as parameters to method calls of an object-oriented language
- > platforms require code to interface with ORB

Figure 4-6: Web Services Based Loosely Coupled System Integration (Source: Coyle, 2003)

A typical Web Services architecture consists of three entities (Figure 4-6), including service registries, service providers and service users (Roy et al, 2001).

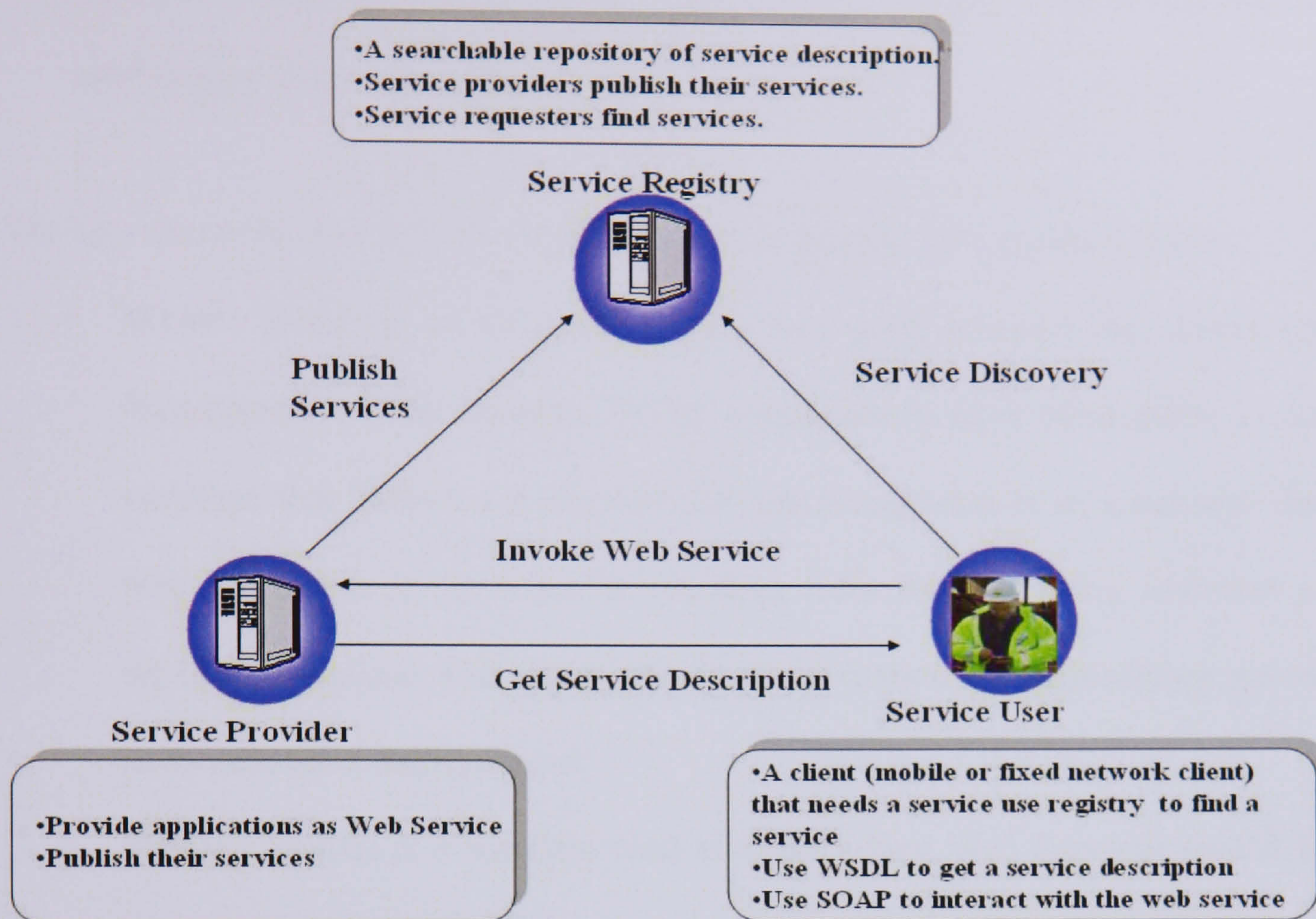


Figure 4-7: Three Entities of Web Services Architecture (Aziz et al,2004)

- **Service Registry** enables an enterprise to describe its businesses, services and rules. Through a registry, businesses describe how they wish to undertake transactions, search for other businesses that provide desired services and integrate with these to undertake a transaction. The API (Application Programming Interface) for registering services is called Universal Discovery and Description Interface (UDDI).
- **Service Providers** publish their services through brokers who maintain registries that clients can look up. Typical standards for describing a service is WSDL (Web Services Definition Language); and

- **Service Users** (Human users or agents) search services in registries and invoke these services using a Web Interface. Simple Object Access Protocol (SOAP) is used to pass object information between applications.

The key standards used in XML Web Service development are explained below:

- **SOAP:** SOAP is an extensible XML messaging protocol that forms the foundation for Web Services. SOAP specifications have three parts: 1) An envelope that defines a framework for describing what is in a message and how to process it; 2) A set of encoding rules for expressing instances of application-defined data types; and 3) A convention for representing remote procedure calls and responses;
- **WSDL:** WSDL is a template used to specify how Web Services should be described and bound. WSDL describes the properties of services such as what the service can do, where it resides, and how to invoke it.
- **UDDI** creates a global, platform-independent, open architecture for describing businesses and services, discovering those businesses and services, and integrating businesses using the Internet. UDDI allows information to be shared about Web Services either internally across the enterprise or across the Internet.

Web Services technology play a key role in the WiSeCon framework because of its key features such as interoperability, dynamic service discovery and reusability.

4.4.1. Dynamic Discovery and Integration Support

Figure 4-7 illustrates a scenario to explain key features of the Web Services

technology in a construction industry context. The following bullet points correspond to the numbers on the Figure 4-7:

- 1. Registry:** In this scenario, UDDI is used as a standard construction project registry. It acts as a yellow pages directory. Construction project partners, register their business (offering company information), shared applications (available for direct access via SOAP over the Internet) and data (project data, inventory data etc) in a shared registry. At a higher level, market place, search engines or software applications will query the registry to discover the services at other companies.
- 2. Querying:** The registry is then queried by mobile construction workers/contractors for available services or data access on an as needed basis.
- 3. Selection:** Mobile worker selects any of the predefined reports/data sources e.g. in this scenario, mobile construction worker has selected a pre-defined report/drawing in the design partners directory.
- 4. Web Services Invocation and Data Exchange:** Mobile user will then bind to the selected service from the design partners data servers. For Web Service invocation, a browser-based front end can be incorporated into construction project portals. UDDI currently uses Web Services security standards, which support current requirements of typical corporate standards for B2B transactions and logging and acknowledgements are exchanged to confirm the transaction.

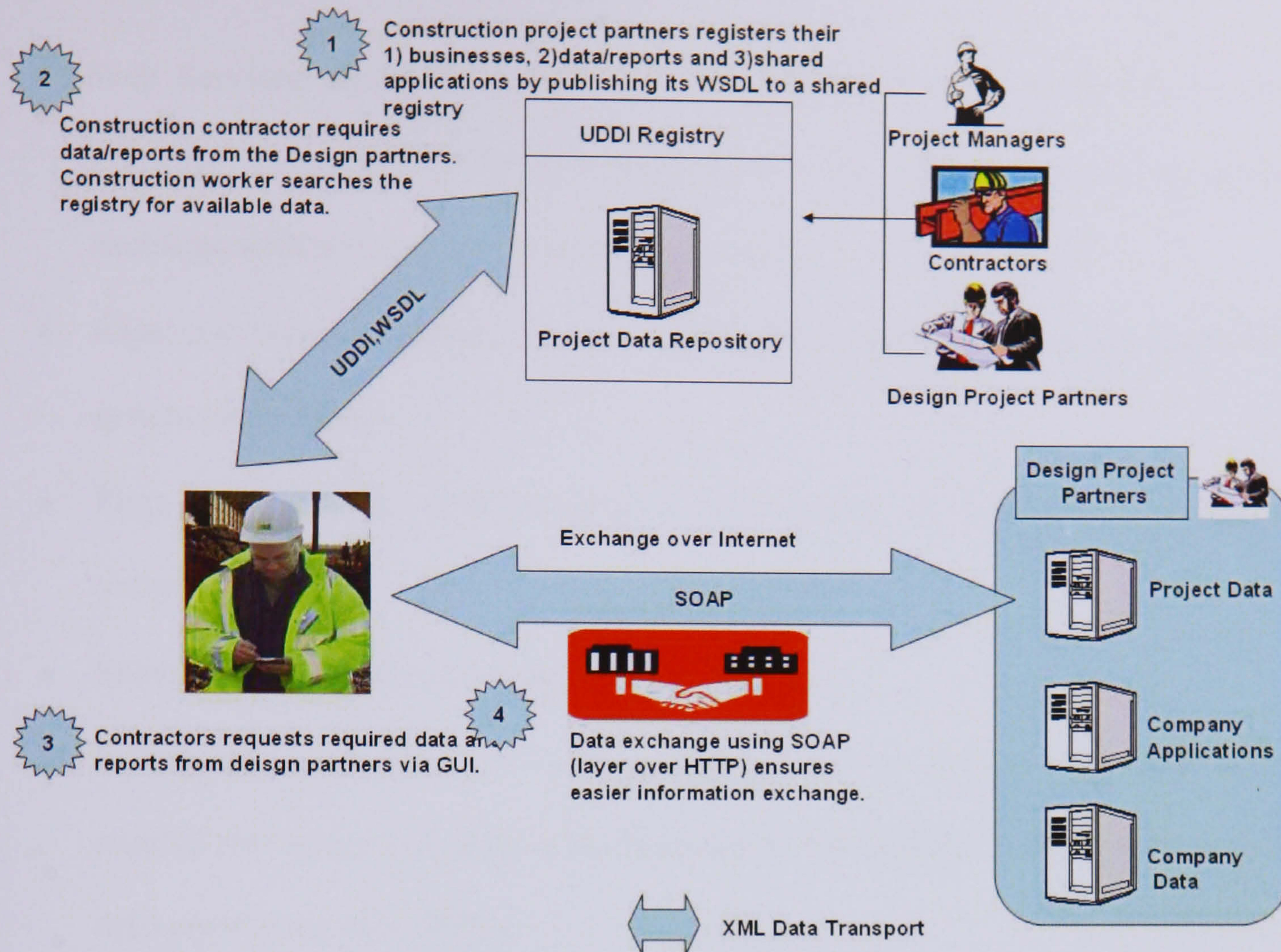


Figure 4-8: Web Services Architecture for Construction Collaboration (Anumba et al, 2003)

The creation of such an online project registry would allow building professionals (e.g architects, engineers, developers, general contractors, sub-contractors and material suppliers) an opportunity to share documents, collaborate on construction projects and procure goods and services online. For instance, project managers can view blueprints online and print relevant sections from a computer – without the downtime and costs associated with commercially printed drawings. This avoids the necessity to physically distribute piles of drawings and documents throughout the supply chain every time the plans get tweaked. Thus construction partners can work on the plans in tandem, saving substantial time each time changes are made. Other advantages of such a system include:

- Huge heterogeneous data collections, complex functionality and a variety of technologies can be integrated through Web Services standards;

- Web Services allow for a new and standardised method of automated data exchange. This results in the significant reduction in manual efforts in document exchange with project partners and other parties;
- Improved communications between construction project partners by improved system integration;
- Huge reduction in costs associated with setting up connections between companies;
- Much faster to agree and establish data exchange;
- Packaging construction software applications as Web Services can potentially remove the barriers of geographic boundaries and expedite construction project delivery (Cheng et al, 2003);
- Web Services loose coupling approach can be used in civil engineering application development, since applications are constantly evolving (Peng et al, 2003); and
- Web Services can improve the performance of a construction supply chain by enhancing information transparency (Min et al, 2002).

In recent years, many research projects have focused on the application of Web Service technology to provide automated discovery and integration support. The E-Cognos (Lima et al, 2003) project used the Web Services model as a primary means for system component interaction and application integration. Using a system dynamics model, Cope et al. (2002) describe an implementation of UDDI registries to test their ability to handle product manufacturers and suppliers in an information brokering architecture. In the ISTforCE project, Web Service level integration was used for Computer Aided Construction work (Cerovsek et al, 2002). XML was used as an information exchange

mechanism while an ontology-based framework was used to support browsing and explanation capabilities. Cheng et al (2003) developed a prototype to illustrate the integration of distributed project management applications as Web Services. PSL (Process Specification Language) was used as an information interchange standard.

4.4.2. Application Integration

Web Services technology can also play a key role in integrating mobile applications with the existing desktop based ICT infrastructure used by the construction enterprises. Existing architectures in construction enterprises are based on multiple technology domains. The resulting complexity and heterogeneity results in poor integration. Different proprietary applications currently being used in the construction industry, do not have a means of sharing information in real time and cross-disciplinary information is very often manually fed from one system into another. This process is riddled with data duplication and errors and is time-consuming. Such back-end systems, based on multiple technology domains, are a serious handicap when it comes to integrating mobile applications with the desktop based infrastructure.

In recent years, many application providers have tried to address integration problems, by providing Application Programming Interfaces (APIs) with open standards based messaging technologies. This allow programmers to develop the connections to integrate disparate applications. However, this results in tight coupling between the applications.

The Web services approach towards application integration promises to address some of these limitations. Web services based architecture is based on modular components,

with each component representing a specific function. These modular components can be composed into solutions to offer the exact set of features required by a particular context. This raises the prospects for enhanced collaboration in the construction industry, as companies can combine their Web Services with that of partners depending on the project requirements. Another example is supply chain integration. Instead of having people constantly searching for business partners a suitable Web service infrastructure would make it possible to do this automatically under defined constraints. The XML Web Services architecture can be used for a wide range of scenarios, from B2B and Enterprise Application Integration (EAI) solutions to peer-to-peer applications and Business to Consumer (B2C) services. Table 4-3 illustrates three tiers of Web Services level integration.

Table 4-3: Three tiers of Web Services interoperability

Three tiers of XML Web services Integration
<p>Tier 1 : Enterprise Application Integration (EAI)</p> <ul style="list-style-type: none"> • Construction enterprises can use XML Web Services to integrate internal applications. Web Services can be used to interface with back-end systems (project portals, management systems, etc). • Using Web Services will allow construction to expose legacy applications to business applications in heterogeneous environments without having to rewrite significant amounts of code. • Advantages include acceleration and reduction in the cost of integration (Web Services-based EAI is cost-effective in comparison with other integration methods), savings on infrastructure deployment, management costs, reduction in skill requirements and improved reuse.
<p>Tier 2: Interoperability with Key Partners (B2B Integration)</p> <ul style="list-style-type: none"> • To integrate with partners outside the company • XML Web Services allow for interoperability between applications across the public Internet. • Key application areas include integration with partners and suppliers and supply chain rationalization. • Because of the lack of broadly-adopted specifications and ontologies, construction companies must evolve agreed semantics on business transaction.
<p>Tier 3: Interoperability across Multiple Companies (B2B and B2C)</p> <ul style="list-style-type: none"> • Construction companies extend their computing out to more partners and customers. • Lack of broadly-adopted specifications for security, routing and other necessary capabilities need to be addressed before B2B or B2C level integration. • Key advantages include integrating diverse contents and reducing the cost of content delivery

4.4.3. Suitable for Developing Mobile Applications

There are different models for Web Services interaction as described in Table 4-4.

Table 4-4: Web Services Interaction Patterns (Source: Rosenblatt et al, 2002)

XML Web Services- Interaction Patterns	
Client-to-Client:	“Smart” clients or devices can host and apply XML Web Services that allow data to be shared anywhere, anytime
Client-to-Server	XML Web Services can share data from a server application to a desktop or mobile computing device via the Internet.
Server-to-Server	XML Web Services provide a common interface between existing applications within an environment of independent servers.
Service-to-Service	XML Web Services can work together in sequence to create a more complex data operation.

One of the most commonly used model is the Client-to-Server model, in which the client is charged with a minimal amount of processing power. This model particularly suits mobile application development, as mobile devices are constrained by power, bandwidth, memory, and processing power. For these reasons, in recent years, there is a growing interest in making mobile devices capable of accessing Web Services over wireless networks (e.g. Dahlem et al, 2002; Pilioura et al, 2003). Together, both the Semantic Web and Web Services open up new possibilities for leveraging the capabilities of mobile computing with the Semantic Web supporting contextual meaning and Web Services technologies allowing registration and discovery of services based on mobile context (Coyle, 2002) (Fig 4-8). Also, Aziz et al (2003) has discussed various scenarios for the application of the Semantic Web and Web Services technologies to support mobile construction workers.

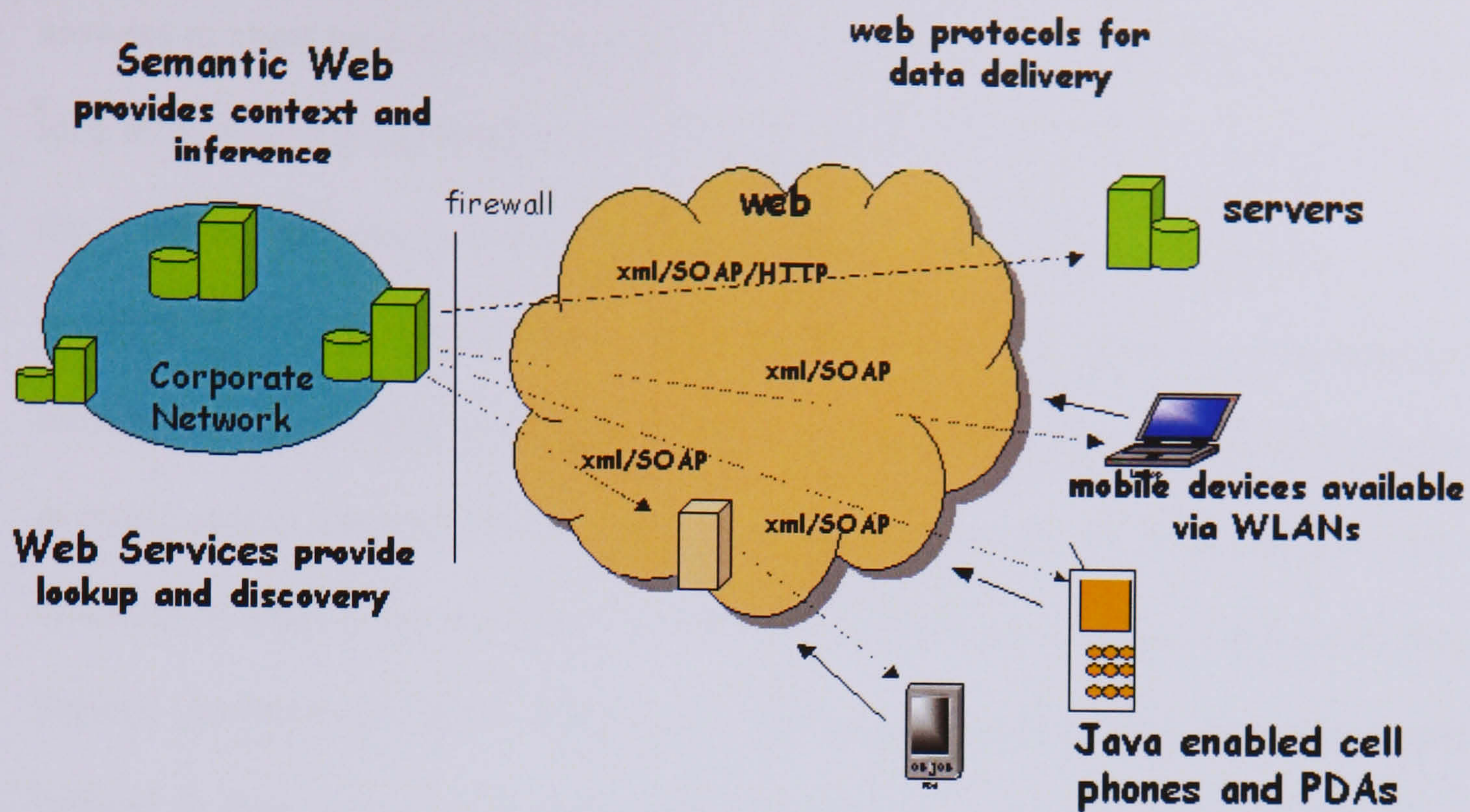


Figure 4-9: The Semantic Web and the Web Services opens new possibilities for mobile computing (Coyle, 2002a)

4.5. Agent Based Technologies

An agent is a self-contained program capable of controlling its own decision-making and acting based on its perception of its environment, in pursuit of one or more objectives (Wooldridge et al, 1995). In many cases, several agents are required to work in concert, resulting in a multi-agent system (MAS). Agent based technologies help in the realisation of the vision of the Semantic Web by helping people create many agents that collect Web content from diverse sources, process the information and exchange the results with other programs (Berners-Lee et al, 2001). Semantic Web technologies will enable automated agents to reason about Web content, and produce an intelligent response to unforeseen situations.

In the mobile construction environment, agents will be essential in helping the user to use highly specific data and services on an as-needed basis. For instance, delivering

answers to short term queries, such as work related tasks, and yet still being aware of long term project goals to be satisfied. Also, agent based technologies are important in the construction industry context because a typical construction collaboration scenario is inherently distributed in terms of geography, knowledge, function, expertise and information. The notion of a (multi) agent-based system provides a natural metaphor to match such distribution. In a collaborative construction environment, agents will be essential in addressing the issues of security, negotiation, personalisation and Web Service procurement (Aziz et al, 2003). These agents will ensure semantics based linkage to data resources, thereby increasing the level of knowledge identification. Agents can also help in preventing the user from being overwhelmed by irrelevant information, using rule based filtering and adaptation of information to individual context and preferences.

4.5.1. Agent Based Systems – Related Work

Ren & Anumba (2004) reviewed the development and applications of MAS in construction. Sadeh et al (2002) created a Semantic Web environment that revolved around a collection of customisable agents capable of automatically discovering and accessing Intranet and Internet services as they assist their users in carrying out different tasks. Dogac et al (2002) developed an infrastructure to describe semantically-defined Web Services available to mobile devices through agent technology and service registries. Cheng et al (2002) developed an architecture to make Web Services more convenient and efficient to use on mobile devices. The architecture integrates mobile agents with Web Services to make use of location information in the Web Service architecture. Maamar et al (2001) investigated techniques and solutions that could support stationary and mobile users in a secure

wireless e-commerce environment using agents and other Semantic Web technologies. The concept of intelligent agents is also being considered in a diverse range of sub-disciplines of information technology, including software engineering, computer networks, human computer interaction, distributed and concurrent systems, mobile systems, tele-matics and computer supported cooperative work.

4.5.2. Relevance of the Agent-Based Technologies for the WiSeCon Framework

Agent-based technologies are central to the WiSeCon framework, and are vital to achieve the vision of context-aware information delivery for mobile workers. A typical context-aware information delivery scenario is inherently distributed in terms of geography, knowledge, and information sources. The (multi) agent-based system plays a critical role in integrating such distributed resources and in provision of specific data and services to mobile workers, thereby helping mobile workers to achieve elements of the construction plan. It is predicted that in the future the Semantic Web will turn the entire collection of Web Services from the existing dormant mass of information the users need to surf, browse and discover, into a dynamic set of capabilities serving the mobile user in fulfilling their personal needs according to their profile and context (Dogac et al, 2003). In such a scenario, agents have to play a key role in addressing the issues of security, negotiation, personalisation and Web Service procurement (Aziz et al, 2005). In the WiSeCon framework, task-specific agents are capable of delivering answers to worker's short term queries, such as work related tasks, and yet still being aware of long term project goals to be satisfied. The convergence of the Semantic Web and Agent based technologies also ensure a semantics based linkage to data resources, thereby increasing the level of knowledge identification. Agents can also help in preventing

the mobile worker from being overwhelmed by irrelevant information, using rule based filtering and adaptation of information to individual context and preferences.

4.6. Discussion and Summary

The technologies discussed in this chapter constitute the building blocks for the WiSeCon framework, which would allow provision of highly specific and customised information to mobile workers based on an intelligent interpretation of their context. The application of the Semantic Web technologies, based on creation and use of common ontologies provide a mechanism for integration and shared use of information and resources. The Web Services-based solutions provide low cost service discovery and application integration opportunity, both within the enterprise, as well as with external project partners and suppliers. Web Services open standards-based dynamic discovery and integration is starting to get wide support from the construction industry. Agent based technologies provide a useful means of integration and coordination of services, while context-aware computing provides a key filtering mechanism to deliver relevant data to users. The WiSeCon framework strongly links the aforementioned enabling technologies. Alongside the technology convergence, improvements in wireless communication technologies allow enhanced connectivity, allowing for anytime, anyplace connectivity. Together, these technologies provide a comprehensive approach to support mobile workers.

Chapter 5: Scenario Generation and Validation

5.1. Introduction

This chapter presents future scenarios illustrating the use of context-aware technologies in realistic construction situations. These scenarios are set in a 10 year time-frame from the perspective of widespread industrial deployment and are analysed, by bringing together the perspective of experts from different backgrounds. During the analysis the scenarios are used purely as challenges, without regard or emphasis that one scenario is more or less probable than another. The key objective of the analysis was to pose the question of next generation context-aware mobile applications in the construction industry and to identify the industry's needs and application areas with the maximum potential. This analysis is subsequently used in Chapter 6 to obtain end-user requirements for the system development.

5.2. Scenario Generation

The research method used for generating different scenarios was explained previously in section 2.7.2. Each scenario was based on various enabling technologies, as discussed in Chapter 3 and Chapter 4. Table 5-1 summarises key technologies underlying each scenario.

Table 5-1: Key Technologies Underlying the Scenarios

Technology Scenarios	Standard Manufactured Component Supply	Project Document Management	Third Party Services Provision	Construction Task Automation	Intelligent Construction Site
Wireless Communications	√ ¹⁰	√	√	√	√
Semantic Data Description (to enable intelligent searching/integration)	√	√		√	
Web Services (for dynamic discovery and integration)	√	√	√	√	
Agents (to represent humans in virtual domain)	√	√		√	
Personalisation- (System knows who the user is and adapts contents accordingly)	√	√			√
Ubiquitous Intelligence (intelligent surroundings)					√
Context-awareness (knows the user's context)					√

5.3. Scenarios

This section presents five different scenarios, illustrating the use of technologies in typical construction situations including supply chain (Section 5.3.1), project document management (Section 5.3.2), third-party services provision (Section 5.3.3), construction task automation (Section 5.3.4), and intelligent construction site (Scenario 5.3.6).

5.3.1. Standard Manufactured Component Supply

This scenario illustrates the case of a mobile construction worker, generating a purchase order for windows. It is assumed, that the mobile worker is interested in

¹⁰ A tick-mark sign indicates that a particular technology was used in the corresponding scenario.

ordering a standard size window (not a bespoke component). The following numbers illustrate the chronology of interaction, and correspond to the numbers in Figure 5-1:

1. Using a mobile device, the worker first connects to the corporate procurement application using a broad band wireless connection, and instructs his Semantic Web agent to search for the approved windows' suppliers. The user can disconnect from the network after this stage. In this scenario, the mobile device does not need to support thick client functionality, as the logic and data processing resides on the wired networks and the workload is passed to the user agent on the wired network. This will relieve the mobile device of the time and processor consuming Web services related tasks like service discovery and negotiation.
2. A Semantic Web-based procurement agent plays the role of a mobile worker representative in the fixed network infrastructure. These agents will be intelligent and capable of making decisions on behalf of users.
3. The procurement agent obtains the information about the windows suppliers using a popular construction electronic market registry, which contains a list of approved suppliers. It is envisaged that the trading registry is based on the Semantic Web technologies, which will allow the suppliers to map the data about their products and services into an ontology, used in the marketplace. These ontologies will define the meanings of the terms used in the market place and the rules of data exchange. After mapping, the data will be published through electronic market registries. Such semantic description using ontologies is important, because the service discovery process can happen only when there is a common language to describe a service in a way that lets other agents "understand" both the function offered and how to take advantage of it (Berners-Lee et al, 2001).

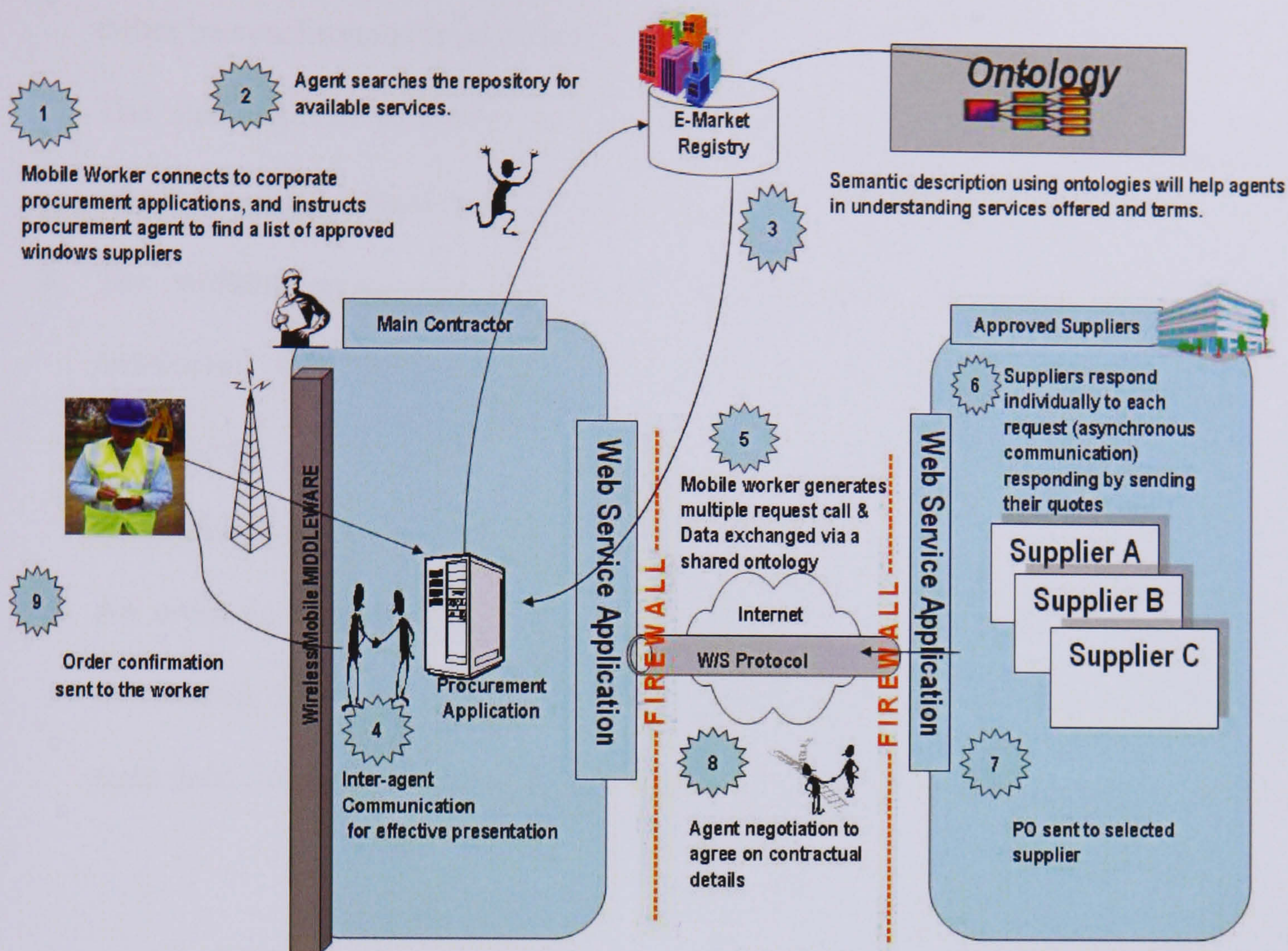


Figure 5-1: Standard Component Supply Scenarios

4. The list of potential suppliers is then passed from the procurement agent to a personalisation agent, which renders the information on the workers' device as per user preferences (e.g. language, device type, location, level of detail, etc). Such transfer of information between agents is possible using the Semantic Web technologies, which provide the framework for typical processes involving number of agents, in which sub-assemblies of information are passed from one agent to another, each one "adding value" to construct the final product requested by the end user (Berners-Lee et al, 2001).
5. In this scenario, the mobile worker decides to make multiple request calls to three approved suppliers to provide their quotes as per the specifications. Data is exchanged between corporate procurement application and suppliers through a shared ontology (e.g. aecXML).

6. Suppliers respond individually by sending their quotes. Such communication can either be synchronous or asynchronous.
7. The site engineer evaluates bids from the suppliers. The best quotes are then selected and a purchase order is generated.
8. The workers' agent and the window suppliers' agent negotiate using shared ontologies, and agree on payment of services and other contractual details. Underlying semantics will ensure intelligent inter agent communication/negotiation.
9. An order confirmation is sent back to the buyer, with delivery information. A monitoring agent will monitor the order, ensuring products are delivery by the right date. Any discrepancies are notified to the project manager.

5.3.2. Project Document Management

This scenario illustrates the case of a typical construction project, which generates an enormous amount of documents, from technical drawings and legal contracts to purchase orders, change orders (CO), Requests for Information (RFI) and permits and schedules. The application of semantic Web services based architecture for handling RFI is discussed. The following numbers correspond to those in the Figure 5-2:

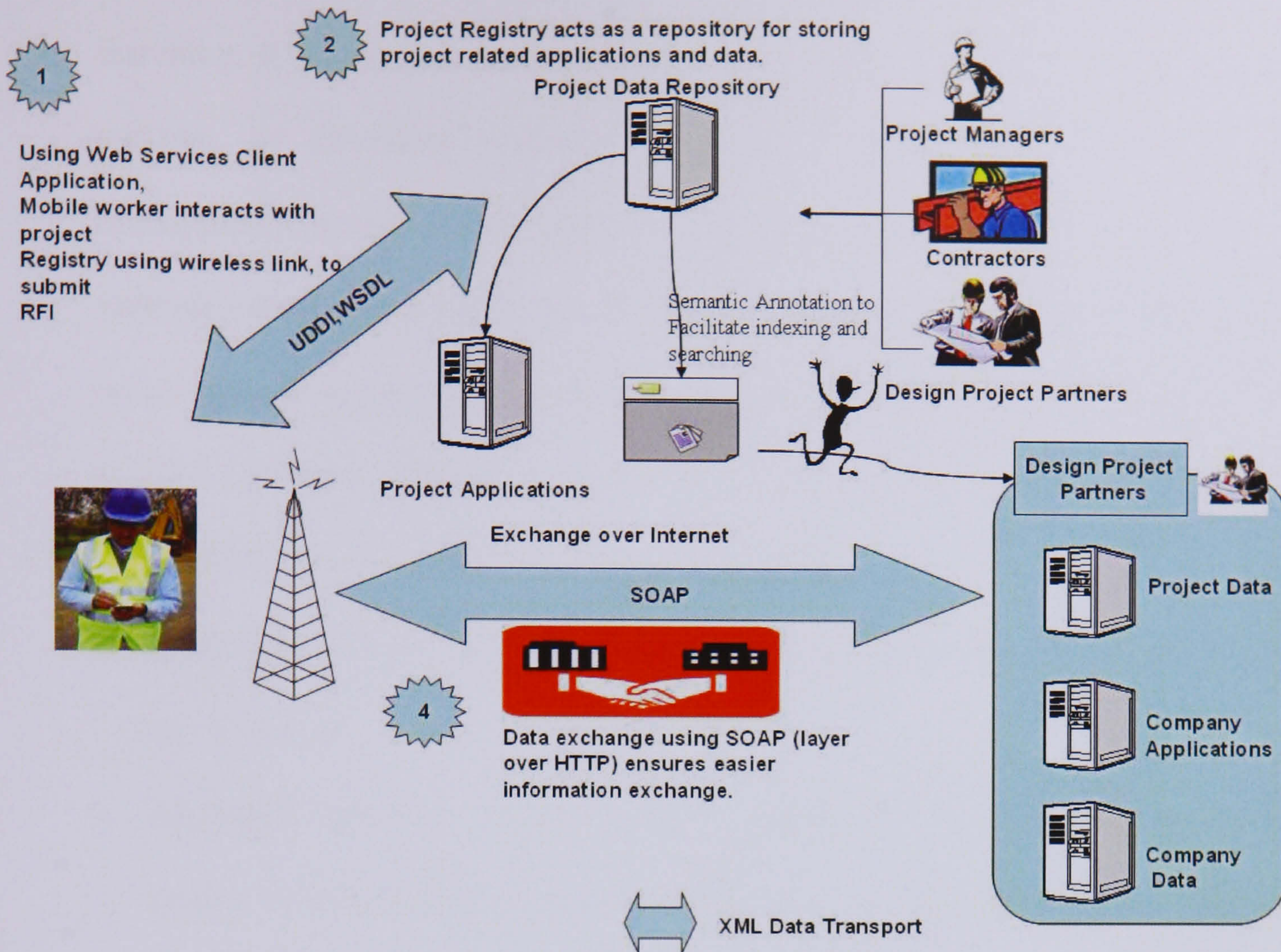


Figure 5-2: Project Document Management

1. In this scenario, the site engineer wants complete details of a joint in a roof joist drawing. Using a Web service client application, the site engineer interacts with the project registry, over the wireless network (e.g. WLAN, GPRS/UMTS), to submit a RFI. An audio and video annotation is attached to the RFI, further explaining the nature of the request.
2. The RFI is recorded in the project registry. An industry standard (e.g. UDDI) is used to define a construction project data registry. It will act as a shared repository for registering all project related data (project data, inventory data, Drawings, Request for Information, CO etc) and shared applications (available for direct access via Web services protocols over the Internet).
3. Semantic annotation using ontologies of all project documents such as request for information, change orders, drawings, images, multi-media, permits etc. is envisaged in this scenario. These annotations would facilitate indexing and

searching. It would also enable improved ways of information submission and retrieval, by describing resources, and links between them. Such semantic description will also enable agents to intelligently synthesise the content from multiple information sources, on ad hoc and on demand basis. Similar approaches on semantic description of resources exist elsewhere, including :

- *SCULPTEUR* (Addis et al,2003), which aims to create a semantic layer for distributed multi-media information management;
 - *ARTISTE* (Artiste, 2003), which developed an image retrieval system, based on meta data;
 - *MUMMY* (Mummy, 2003), which employs ontology-based solutions to enable mobile, personalised knowledge management based on the usage of multimedia; and
 - *ANNOTEA* (Koivunen et al,2003) provide means for users to share communication about Web documents by attaching external annotation metadata to the documents.
4. In this scenario, the semantic description of RFI will enable agents to decide, that RFI has to be directed to the design partners. The agent will also help users to track and monitor the RFI throughout its lifecycle.
 5. Design partners will take appropriate action on the RFI asynchronously. Completion of RFI is then recorded in project registry. Push based telecom technologies such as SMS (Short Messaging Services) can then be used to update the worker of RFI progress.

Using Web Services protocol, the mobile worker then connects to the project servers using his mobile device, to download the latest version of the drawing. The key

advantages of semantic Web description in this scenario include reduced RFI cycle time, RFI's electronic trail, task automation and quicker searching through semantic annotations.

5.3.3. Third Party Services Provision

This scenario (Figure 5-3) illustrates the case of a construction application development firm, which wants to make its engineering application software available to clients as a service.

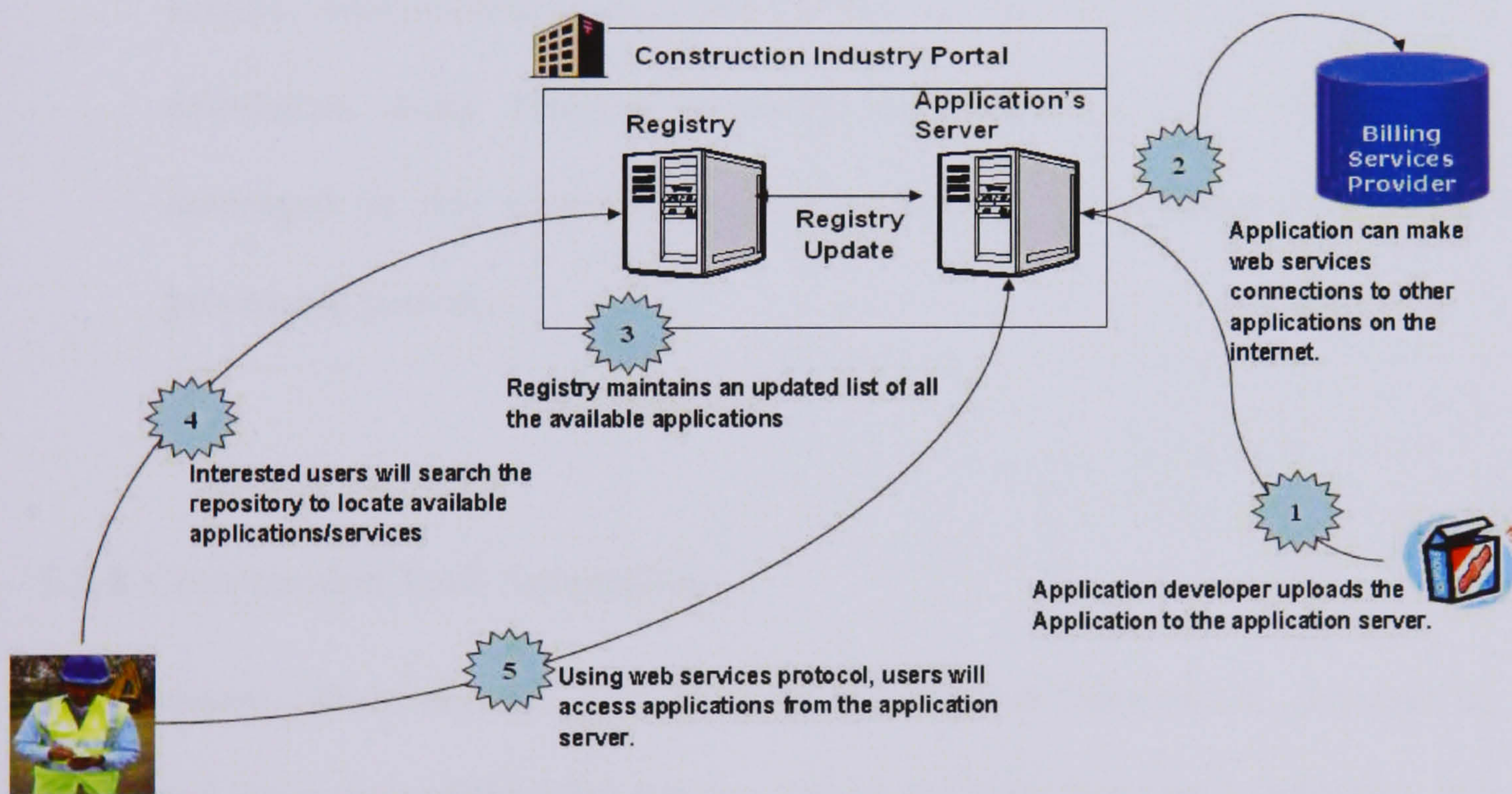


Figure 5-3: Third Party Services Provision

1. An engineering analysis application developer first uploads the application to the application server. In this scenario, the application hosting support is provided by a construction industry application's Web portal. Using an open standards interface, developers can also monitor user status information etc.

2. The applications can be standalone or can make connections to other Web services on the Internet (e.g. billing services).
3. The application is stored in the server, and entry is updated in the corresponding registry. The registry maintains the list of available applications and description of how to access them.
4. Interested users (wired or wireless) will search the repository to locate available services.
5. Using Web Service protocols, users can access applications from the application server. In this case, the mobile worker passes parameters for engineering analysis calculations to the application residing on the application servers. Analysis will be done and the user will be sent back the results of the calculation using Telecom networks. Separation of logic and data, as envisaged in this scenario charge the clients with minimal memory and processing powers.

5.3.4. Construction Task Automation

This scenario illustrates the case of construction task automation, through the automated invocation of the Web Service. Using the Web Services architecture, it is possible to implement automated steps into business process workflows. Current initiatives like DAML-S (Ankolekar et al, 2001) are focusing on automated invocation of semantically aware Web services. Such invocation can be triggered by a timed event or by an agent, as illustrated in Figure 5-4.

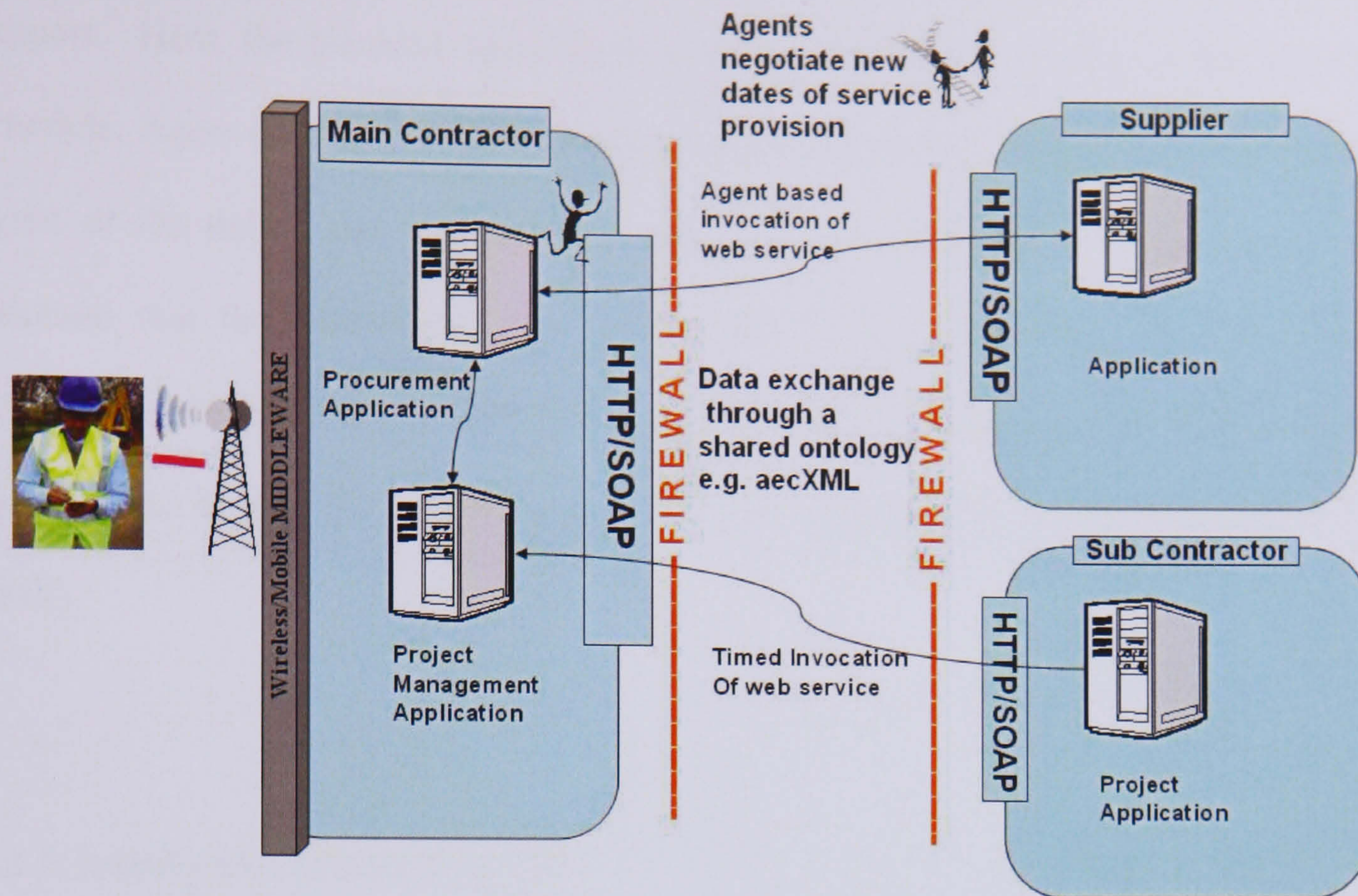


Figure 5-4: Construction Task Automation

Main Contractor- Sub Contractor Communication: In this case, the main contractor requests project progress, work schedules and deployment of labour reports from a sub contractor's project management application at the end of the shift, through an programmatically timed process. Business rules will define rules for data exchange. Use of shared ontologies will ensure standardisation of inputs and outputs to project management systems. Using push based technologies, data on project manager's mobile device is synchronised with the servers.

Main Contractor- Concrete Supplier Communication: In this variation of above case, a Web service is invoked through an agent. The semantic description of project documents, schedules etc. is envisaged. Such semantic awareness will generate greater visibility and will help agents to generate critical information for the decision

support. Here, the planning agent have noted a time lag of one day in the project schedule. Agent invokes the Web service of concrete supplier, notifying the suppliers agent of the delay, and renegotiating new date, time and terms of service. It is assumed that the main contractor and suppliers' data is available in a machine processable format, which allows intelligent agent communication. The project manager can then be updated of the new schedule using push based technologies (e.g. SMS).

5.3.5. Intelligent Construction Site

This scenario focuses on the creation of an intelligent work environment for construction workers, by bringing together key technology threads such as Ubiquitous Computing, Wireless Sensor Networking, tagging and location tracking technologies, as part of the context-capture layer in the WiSeCon framework. Better awareness of the user-context, as enabled by the aforementioned technologies can be used for a wide range of applications on the construction site, including those that increase human productivity (such as location-tracking of tools), increase safety on the construction site (such as tracking workers near machines) and automate various tasks (such as automated data capture).

In this scenario it is envisaged that each item on the construction site (e.g. equipment, vehicle, materials, etc) is embedded with an intelligent tag. Tags identify each object and also helps in its location determination. A real-time location tracking system determines the position of people and objects. Such an infrastructure can possibly be used for a wide-range of applications. For instance, based on the existing location,

profile and task of the mobile worker, relevant information can be delivered. Figure 5-5 illustrates such an application scenario. The system establishes the worker's identity, either through the IP address of the mobile device or through an intelligent tag. (e.g. Worker A who is an electrician or Worker B who is a plumber in Figure 5-5). Also through a location-tracking system, it determines the worker's location (e.g. Zone N or Zone B as defined in Figure 5-5). Based on the captured context, it pushes relevant H&S information and training videos on the worker's mobile device.

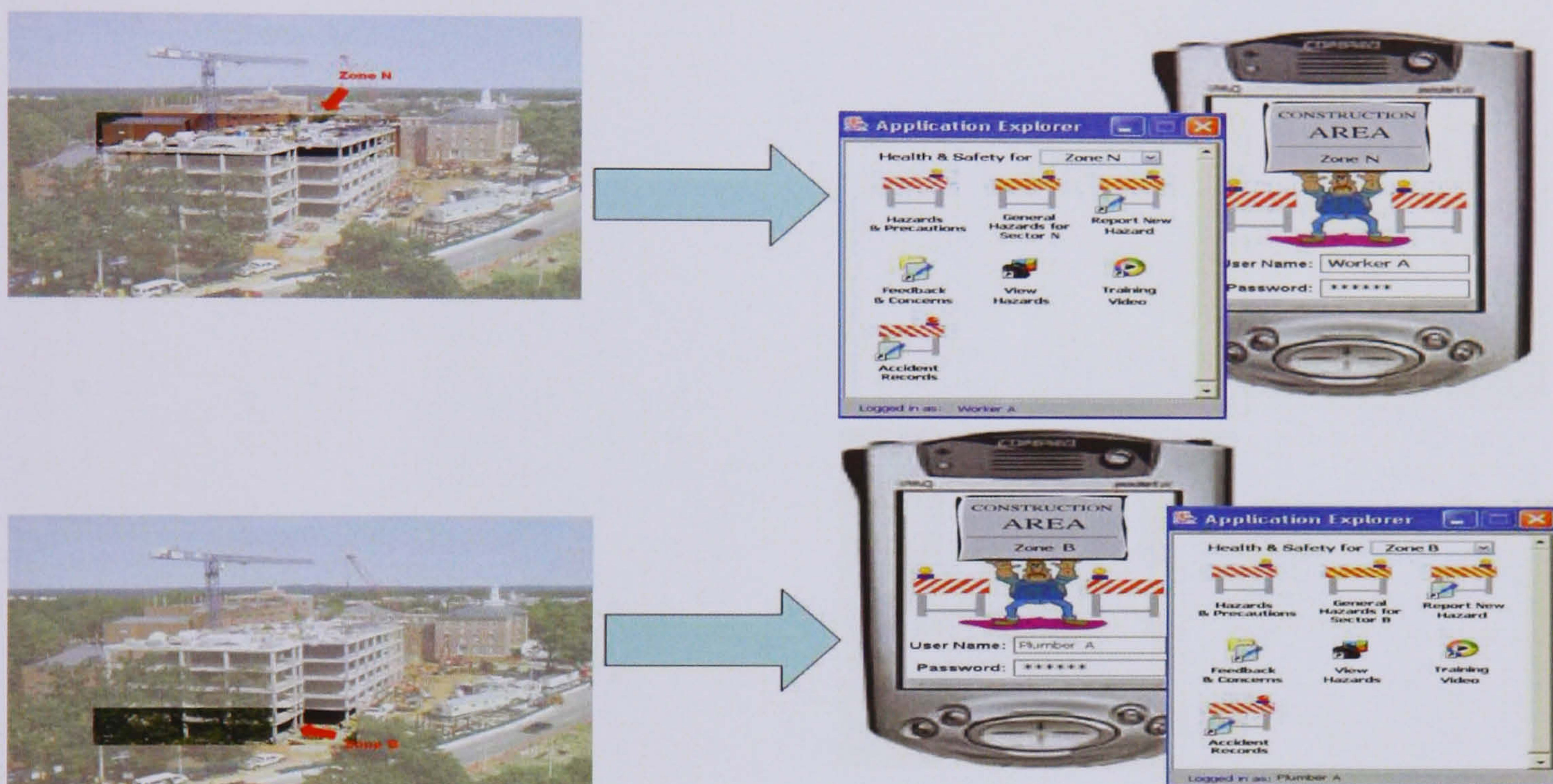


Figure 5-5: Context-aware data delivery

Similarly, it is possible to use such location-tracking system to improve on-site Health and Safety. So for instance, if a site-operative whose training profile suggests that he has not done his induction training approaches a hazardous area close to cranes (Figure 5-6), appropriate warning messages can be generated. Context-aware computing technologies can also be used for other applications such as keeping a tool audit (by recording who last had charge of an expensive equipment) or for improving site-security (e.g. generating appropriate alerts if site equipment is removed from the premises). It is also possible to create virtual reality displays of site, using real time

location tracking of construction equipment and people. This can possibly be used for remote monitoring of on-site activities. Some other possible application scenarios of intelligent construction site include inventory/asset/materials management, remote expert support, remote control and guidance of construction equipment, process control and control of various sensors and actuators.



Figure 5-6: Proximity-Based warning system

5.4. Scenario Validation

The research method followed for the scenario validation process was explained briefly in Section 2.7.3. This section further elaborates on the expert selection and validation process. In order not to undermine the credibility of the research work, it was crucial that the right industry experts were chosen to validate scenarios. An utmost care was taken to choose people with the right expertise and technical knowledge of the construction industry and related wireless Web technologies. Scenarios were validated with 13 experts. On average, the interviewed experts had five or more year of experience in their respective area of expertise. Experts were

selected from different backgrounds as discussed below, to combine different perspectives.

- **Construction Industry Practitioners:** 5 experts were interviewed in this category. Their participation in the validation process ensured that an appropriate construction industry perspective was taken;
- **Technology Experts:** 3 technology experts were interviewed. Their participation ensured that the technology can be applied in an appropriate manner;
- **Construction Academics:** The Scenarios were also evaluated with 5 construction academics. Academics were chosen to validate the scenario because they are usually used to take long-term perspectives as part of their research, which was clearly an advantage at this phase of the research. Also, they are experts within their area of research interests, which enables them to make educated guesses about possible developments in a long term perspective. Three of the five interviewed academics had previous experience of working in the industry.

As this research was conducted as part of the larger WiSECON project, some of the interviewed experts were drawn from the industrial steering of the WiSECON project. Semi-structured interviews were held with identified experts. The idea of organising an expert workshop was not considered feasible because of the busy schedules of the identified experts. During the validation process, each scenario was described as a story in the year 2014 (i.e. in a 10 year time frame), including the chain of events as described in the scenario description. A detailed description of the underlying technology was given before the interviews. Scenarios were subsequently presented to

experts visually and with non-technical language, using animated PowerPoint presentations. A visual description of the scenarios was important to ensure deeper understanding of the issues involved. Formal system design languages like UML are good for the system documentation, but they are generally not well-understood by the wider construction audience and so, were not adopted. Scenarios provided a focal point for both the construction industry and technology experts to relate to the future technology landscape and associated technology issues, and provided a stimulus to discuss related issues and the industry's needs.

During the interviews, the focus was on gathering primarily qualitative data such as expert's perspectives and opinions. Quantitative data was not considered to be of much use in this task, for the reason that the focus during the interviews was to validate the future requirements of context-aware systems and pre-determined answers to questions were not expected. Also, during the interviews, the greater involvement and participation of the interviewees were essential to explore the potential of context-aware services in the construction industry. Thus interviews were loosely structured. According to Bryman & Bill (2003) the advantage of loosely structured interviews is that more complex issues can be probed, answers can be clarified and a more relaxed research atmosphere may result in more in-depth as well as sensitive information. The disadvantages are that the data are time consuming and difficult to collect and analyse and there are greater opportunities for interviewer bias to intervene. In this case, advantages far outweigh the disadvantages. During the interviews the discussions primarily revolved around the scenarios, and the following key questions were discussed:

- Do you think it is a valid scenario? Do you see it happening in the future?;

- What drivers/barriers do you see in the realisation of such a scenario in the construction industry?;
- What kind of steps industry can take to help realisation of this scenario?; and
- Do you see any related issues surrounding this scenario?.

The aforementioned questions were used as a guideline to have a discussion around topics related to context-aware information provision for mobile construction workers and to get the opinions of the industry experts. During the interviews, the topics under discussion were elaborated upon using laddering techniques, to avoid getting standard answers. Laddering is a tool for uncovering subjective causal chains in qualitative interviews (Grunert & Grunert, 1995). In laddering, a series of consecutive probes are used to prompt the respondents to develop causal chains. Scenarios were also validated by publication in a research journal (Aziz et al, 2004). The feedback gathered during the validation processes is presented in the following section.

5.5. Expert Feedback - Scenario Drivers

During the validation process experts were asked to identify specific construction industry applications that can drive the uptake of concepts presented in the scenarios. Table 5-2 presents a summary of the application areas, advantages and other issues corresponding to each scenario, as identified during the interviews. Also, during the interviews, experts identified various industry trends which may drive the uptake of the concepts presented in the scenarios. These drivers are presented in Table 5-3.

Table 5-2: Identified Application Areas

Scenario	Identified application areas	Identified Advantages	Identified Issues
Standard Manufactured Component Supply (Section 5.3.1)	<ul style="list-style-type: none"> • Helping people on the site to contact suppliers • Supporting quantity surveyors in their work. • Specialised Equipment Procurement¹¹ 	<ul style="list-style-type: none"> • An open e-market will ensure competition • Fast delivery • Ability to order from the point of work • Greater visibility across the supply chain 	<ul style="list-style-type: none"> • Speed is not an issue in procurement as there is a great deal of negotiations involved • Scenario assumption that component selection is based entirely on prices is an over-simplification • Information intensive nature of the procurement process may make it difficult to handle it through a Pocket-PC type device • It was suggested that Grid technologies may be useful to address security and trust issues
Project Document Management (Section 5.3.2)	<ul style="list-style-type: none"> • Access to highly specific data • Applicable in cases where information is not available in a ready format (e.g. seeking alternate suggestions from designers on a paint colour). • Quality Control/ Quality Assurance 	<ul style="list-style-type: none"> • Flexible Working¹² • Speeding up of construction process (e.g. RFI processing). • Ability to maintain an audit trail • Rapid access to specific data and improved searching 	<ul style="list-style-type: none"> • The key decisions such as to whom RFI gets forwarded to are being taken by agents. In construction, there is a great deal of tacit knowledge involved and such decisions should not be automated

¹¹ A project manager identified the problems involved in hiring of cranes and other specialised construction equipment. It was highlighted that an e-market registry concept, as presented in Scenario 4.2.1, will make procurement of such specialised services easy and fast.

¹² An expert commented, "If you have got the information available at your fingertips, then possibly you can work from anywhere- from the site, from the office or from your home".

Scenario	Identified application areas	Identified Advantages	Identified Issues
Third Party Services Provision (Section 5.3.3)	<ul style="list-style-type: none"> • Civil Engineering Applications involving lot of computations (e.g. Structural Analysis, Finite Element Analysis applications) • Suitable for wireless applications development¹³ • Project level integration, where different project partners can deliver their applications as services 	<ul style="list-style-type: none"> • Document management (e.g. Retrieving structural, manufacturing, and architectural details at the facilities management stage) • No software piracy • Less maintenance costs, as software will not be owned, rather used on an as-needed basis • Ability to access large markets at a relatively lower cost¹⁴ 	<ul style="list-style-type: none"> • Realisation of such a scenario may require changes in the licensing strategies and the business models
Construction Task Automation (Section 5.3.4)	<ul style="list-style-type: none"> • End of shift reports • Intelligent data processing 	<ul style="list-style-type: none"> • Real time data access • Ability to synchronise data 	<ul style="list-style-type: none"> • It was emphasised that many of the existing project management tools lack the ability to analyse the current project status and to bring required changes according to the changing project conditions in real-time. It was emphasised that the Semantic Web and

¹³ An illustrative comment was, "Remote data processing, as presented in this scenario very much suits the resource constrained mobile devices. As actual processing takes place on the back end servers, mobile device will be charged with minimal amount of battery and processor resources".

¹⁴ It was highlighted that using a service oriented architecture, application developers can sell their products worldwide using the Internet. There will be no need to have large sales force to promote the software usage.

Scenario	Identified application areas	Identified Advantages	Identified Issues
Intelligent Construction Site (Section 5.3.5)	<ul style="list-style-type: none"> • Knowledge Management • Data collection • Bringing intelligence and automation on the construction site • Applicability in all phases of the component life-cycle • Integration with the visualisation technologies • Site Logistics • Automating paper based tasks • Automated data capture. • Health and Safety Applications • Proximity based services • Staff and equipment tracking and management • Disaster management 	<ul style="list-style-type: none"> • Improving Human Computer Interaction through better understanding of user-context • Will facilitate knowledge worker • Improved context-awareness to support less computer literate on-site staff • Possible usage in life cycle stages • Better control of resources through tagging 	<p>agent based technologies can play a key role in this aspect</p> <ul style="list-style-type: none"> • Technology robustness – Suitability for on-site operations • Technology costs • It was suggested that H & S applications can drive the uptake of such technology in the construction industry • It was suggested that tagged information can be used in all phases of the life-cycle including building management and demolition • It was suggested that in a ubiquitous computing environment, standards are important, as different devices/equipment need to inter-communicate. • Privacy concerns

Table 5-3: Key Industry Trends

Identified Industry Trends	Description
<p>Trends towards Electronic Procurement</p>	<p>Recent trends towards electronic procurement were identified as the major drivers of concepts presented in the Scenario 5.3.1. An illustrative comment was, "There are recent trends towards procurement equipments electronically. Globalisation is also driving such trends. Procurement of components such as steel sections is already to a large extent Internet based. As the markets become global, people will start looking wider and wider, in search of the best products, in terms of price, quality and delivery. Market in such a situation will become more competitive. If users can get a better deal through a market registry, probability is that they will go for it. Increasing globalisation will be the key factor in driving down the prices"</p>
<p>Industry move from the 2d to nd Data Modelling</p>	<p>An illustrative comment was, "The limited display size of mobile devices such as Pocket-PCs makes them inappropriate to view detailed construction drawings and documents. The industry move from 2D to nD data modelling will allow the use of data in a variety of formats, making Pocket-PC a useful tool to back-up the paper-based construction drawings and documents. A mobile worker can send a query about a specific aspect related to paper drawings (such as windows dimensions or specific queries such as how deep a hole has to be dug) and can get a response in a format suitable for display on a Pocket-PC screen.</p>
<p>Trends towards Knowledge Management</p>	<p>It was suggested that the increasing awareness of knowledge management amongst the construction firms can drive the application of the Semantic Web technologies in the wireless domain as discussed in the Scenarios 5.3.1 and 5.3.2. An illustrative comment was, "Semantically annotating construction documents with the relevant information can play a critical role in managing construction documents. The Construction Industry is gradually recognising the need for meta-data, and there are already project extranet solutions</p>

Identified Industry Trends	Description
	<p>such as Columbus Viewer from Arup, which allow users to tag documents with XML". Similar comments were made during the discussion of Scenario 5.3.5 where it was mentioned that a better awareness of the context of user activities on-site has the potential to improve knowledge management at the construction site level. It was also suggested that mobile technologies are ideally suited for capturing knowledge from point of work.</p>
<p>Trends towards Delivering Applications As Services</p>	<p>These trends were identified as the key drivers for the concepts presented in the Scenario 5.3.3.</p> <ul style="list-style-type: none"> • A few interviewed experts said, that leading construction companies, including Corus-Group, Arups and BIWTech are already providing some of the applications as services and introducing the concept of buying the CPU time, rather than buying the software application. • It was identified that trends towards delivering applications as services suit both application vendors and users. From the application vendors point of view, it can prevent their biggest concern of application piracy and can also reduce the costs involved in packaging and marketing applications. From the user's perspective, they pay on usage basis, which is more economical. Also, users will download the latest version of the software, thus there is no need for software updates. • It was mentioned that there are sophisticated e-billing solutions available, which allow charging users on per usage basis. • An academic expert mentioned that in future, Grid Computing and Web Services will provide critical infrastructural elements for delivering applications as services.

5.6. Expert Feedback- Scenario Inhibitors

This section presents a summary of various scenario-inhibitors identified during the interviews.

5.6.1. Lack of Automation

It was highlighted that some of the presented concepts (such as e-market registry as discussed in Section 5.3.1 and Web-Services based Automation as discussed in Section 5.3.4) assume a very high level of automation which does not exist in the construction industry at the moment. An illustrative comment was, "In the existing situations, where many contractors still rely on paper-based systems or a very basic ICT infrastructure, realisation of such a scenario seems a long way to go".

5.6.2. Interoperability Issues

Interoperability issues were identified as a major barrier to achieve the vision of an E-market registry (as discussed in the Section 5.3.1) and the use of industry standard ontologies (as discussed in the Section 5.3.2). It was mentioned that the fragmentation existing within the construction industry makes the achievement of such goals even more difficult.

5.6.3. Mobile Communication Limitations

Various mobile communication limitations were identified as inhibitors to the uptake of the concepts presented in the scenarios discussed in Section 5.3. These include:

- **Wireless Bandwidth Issues:** It was suggested that semantically annotating construction documents (as discussed in the Section 5.3.2.) is bandwidth intensive involving a lot of wireless overhead which would slow the download process.
- **Limited display size** of the mobile devices was identified as a major limitation by many experts. It was highlighted that it is important to address the interface and usability issues, as site workers are not usually technically literate and application usability will be the key factor in determining its success. Another expert suggested exploring usage of other devices such as tablet PCs or e-ink¹⁵ (E-ink, 2005) to address the usability concerns.
- **Wireless Networking Issues** such as network coverage and network handover were also identified as potential problems in discussion.
- Other mobile device limitations such as limited battery, memory size and robustness issues were also identified by industry experts.

5.6.4. Information Overload

During the discussions on the Intelligent Construction-Site scenario (Section 5.3.5), possible information overload problems were identified. An illustrative comment was “Obviously we can not use sensors and RFID tags to record every possible detail. This will result in the generation of a lot of useless information. Applications need to be very smart to ensure what information is important, and what needs to be discarded. Otherwise users will switch off such an application and ignore it”. In the WiSeCon

¹⁵ E-ink (E-ink, 05) is a proprietary technology that enable display of electronic information on a paper-like material.

framework, the context-inference layer plays the critical role of information filtering, to ensure that information is handled in an appropriate manner.

5.6.5. Security and Trust Issues

Industry experts identified various security and trust issues that can possibly inhibit the realisation of the concepts presented in the scenarios. A few selected comments include:

- "Security is the one key factor for the success of such an e-market registry (reference to Section 5.3.1). The user authentication is important, as suppliers need to know who their customers are and customers need to know how the suppliers are rated in the market".
- "As much of the corporate data is confidential (reference to the Scenario 4.2.4), Sub-Contractors may not like to provide Main-Contractors free access to the information on their systems. Thus there is a need to create appropriate data views".
- "In this scenario (Section 5.3.1), agents are doing the job of searching and negotiations. There are potential trust issues involved here. Agents have to be trusted across the supply chain, before they can be deployed".
- "If you are giving too much information about yourself such as who you are, where you are, what device you are using, what task you are involved in, there is an obvious need for protection, to ensure that this information is not misused (reference to the Section 5.3.5)".

5.6.6. Cultural Issues

It was identified during the interviews that various cultural issues specific to the construction industry may prove to be a barrier to the concepts presented in the scenarios. An illustrative comment was, "People do not like to be told what to do. This is especially true about the project managers- And if you make technology play the role of a big brother, it will create a lot of resentment".

5.6.7. Industry's Long-Term Vision of Partnering the Supply Chain

It was emphasised by an industry expert that the concept of an open-for-all e-market registry (reference to Section 5.3.1) goes against the construction industry's long-term vision of partnering the supply chain. He said, "This vision envisages contractors working in close collaboration with contractors. Also, there is a push in the industry of not doing things by the lowest price which also prove an inhibitor to the creation of such an e-market registry". To address such concerns, it is possible to limit the scope of the e-market registry only to the pre-approved suppliers.

5.6.8. Fragmented Nature of the Construction Industry

Problems arising from the fragmented nature of the construction industry were highlighted by many evaluators. An illustrative comment was, "Because of the fragmented nature of the construction industry, the probability of having a construction industry portal where all the applications will reside is very low. Similar over inflated claims were made at the advent of 3G technology, and we have yet to see any realistic application. I think it is probable that such a concept will be

implemented at a company or a project level". Also, other issues were identified, including:

- Issue of who will drive the technology uptake movement forward- client, contractor or designers;
- Getting everyone in the supply chain to use these technologies; and
- Issue of who will bear the cost of technology deployment and maintenance.

5.6.9. Business Process Related Issues

Various issues were discussed under this heading, which are discussed as below:

- **Complex Approval Chains:** It was highlighted that the site-staff usually do not have the authority to take the key decisions such as procurement of goods (as discussed in the Section 5.3.1) or generation of RFIs (as discussed in the Section 5.3.2). Usually they need to consult people in the back-office which often slows down the process. An illustrative comment was, "RFI handling process may take several different routes, depending on the organisational practices. The scenario needs to have a degree of flexibility, to handle different approval routes".
- **Data-Intensive Nature of the Construction Processes:** In view of an expert, construction processes such as goods procurement and RFI generation (as discussed in the Sections 5.3.1 and 5.3.2) are very data intensive. It is more likely that the procurement work will be undertaken by someone using a desktop based system, with a much detailed availability of information, rather than someone merely carrying a mobile device. However, in the author's view, with the advent of broadband wireless technologies and increasingly powerful mobile devices, it is becoming possible to provide desktop type functionality through mobile

devices such as Tablet PCs, Procurement etc. Providing procurement support to mobile workers will ensure greater flexibility.

- **Lack of Documented Knowledge:** An illustrative comment from a project manager was that, "In the scenarios, you have assumed too much of the management control, which is not always possible on a construction project. For instance, a lot of information is available to the procurement agent to make intelligent decisions. Such higher level of detailed information and detailed control do not exist on the construction site. Lot of practical knowledge exists in tacit form, and exists only in peoples' heads. This knowledge or experience is not in the written format. People do not write down everything. And this tacit knowledge is crucial in the decision making process. Some processes may be more suitable for automation, but you can not automate every single process".
- **Cost Uncertainty and Issues:** An illustrative comment was, "Very often, costs of the project are agreed at the bidding stage. On-Demand use of mobile phones and associated wireless Web services (as suggested in the Section 5.3.3) may result in the cost of the project escalating dramatically over the course of time. In comparison, a fixed monthly price would be better as the prices are clear at the project outset. It is important to look into the business model for such an application delivery".

5.7. Discussion and Summary

This chapter presented the scenarios of future context-aware information delivery services. The scenarios were validated with a group of selected construction industry and technology experts. The multidisciplinary make up of experts served to combine

the perspectives from different backgrounds. During the validation process, the scenarios served the purpose of helping the interviewees think out-of-the-box (as described previously in Section 2.7.2) and resulted in more visionary thinking than the alternative of just asking interviewees for their views on future context-aware services. Also, the visual description of scenarios was a very effective way to communicate with the experts. It allowed them to see through the whole process and where the technology fits into the existing process, thereby improving communication and validation. To a certain degree, there was a consistency in the various trends identified by the experts during the interviews. Security and usability issues were particularly highlighted on many occasions during the discussions. Also, it became clear during the interviews that there is a keen interest in the industry in the intelligent construction-site scenario (Scenario 5.3.5) and various enabling technologies such as location-tracking, RFID and ubiquitous computing. Various application areas for the concepts presented in the scenarios were identified. Also, various uncertainties related to the concepts presented in the scenarios were highlighted. This necessitates the need to take both the technology and the construction industry perspective in any future application development. The next chapter further analyses the interview data using the SUNA method, to identify the construction industry's needs for future context-aware services. These needs are subsequently used as defining dimensions for the system design and architecture development.

Chapter 6: System Design

6.1. Introduction

This chapter describes the design and architecture of the prototype system. The architecture encompasses the elements making up a system and the manner in which they work together to provide the functionality of the system (Alhir, 2003). A scenario-based user needs analysis (Helvert et al, 2003) approach is employed to translate the end-user needs identified during the scenario-validation process (as documented in Chapter 5) into system design goals. The system architecture is subsequently based on these design goals. An implementation scenario is discussed and the conceptual modelling is depicted in UML with a use-case driven approach, to illustrate the functional requirements of the system. Various system design choices are discussed and a physical architecture is presented.

6.2. Identification of the User Needs

The scenarios discussed in Chapter 5 were meant to provide a vision of future context-aware mobile services. They also illustrated the key benefits of the functions and features of these services in realistic AEC/FM scenarios. Subsequent face-to-face semi-structured interviews with construction industry experts ensured a rigorous critique of the scenarios. These expert interviews were a source of knowledge and perspectives, and helped to identify the user needs and various inhibitors and drivers for each scenario in the AEC/FM industry context. It is from the analysis of the interview data, that a common set of user needs is drawn (Table 6.1), using the SUNA method (as explained in Section 2.7.4). These needs represented functional and

technical requirements for future context-aware information delivery services for mobile construction workers and were subsequently translated into the system design goals (Section 6.3), which acted as a key input to the design and evaluation of the prototype system. Table 6.1 presents end-user needs and the associated rationale. Probable technologies that can be used to address these needs are listed. It is not an exhaustive list, and suggests some technologies that can possibly be used to address end-user needs. Some of the identified needs are crucial from the viewpoint of the prototype deployment, while others are desirable but not essential. Thus needs are categorised as In-Scope (needs that the system must address) and Out-of-Scope (needs that are outside the scope of the architecture). The categorisation is also based on each need's consistency with the original research aims and its relevance for the prototype development. Also, technical and resource limitations for the prototype deployment are considered.

To categorise various needs discussed in Table 6.1, an end-user needs hierarchy (Figure 6-1) was drawn. A user needs hierarchy is an organised representation of the user needs. In the SUNA process, the needs hierarchy plays two key roles (Helvert et al, 2003):

1. It informs the process of scoping the system boundaries (i.e. what is being developed and what is not); and
2. It represents an interface to the structured design and development method.

The approach taken here involved examining the identified needs in Table 6-1, and identifying logical groups of needs that could be collected under a single heading.

Table 6-1: Description of User Needs

No.	User Need	Rationale	Techniques & Technologies	In-Scope/Out-of-Scope
Nd ¹⁶ . 1.	Need to provide mobile workers access to highly specific data on an as-needed basis	Mobile devices are resource constrained. Thus, the system needs to be smart enough to retrieve the relevant data based on the worker's context.	Semantic Web, Context-awareness, Web Services, Agent Technologies	In-Scope Prototype implementation will address some aspects of intelligent data access.
Nd. 2.	Need to have people in the decision chain	There is lot of tacit knowledge involved in construction, thus the final decision must always reside with the people. However, certain routine tasks can be automated using appropriate technologies.	Human-centric design methods	Out-Of-Scope Prototype will empower the mobile worker in the decision making process- However, it will not take decision on the workers' behalf.
Nd. 3.	Need for a construction e-market place and automated discovery and integration	There is a need for a construction e-market place, where users can discover service providers and their services. Trends towards global procurement also necessitate such an e-market place.	Web Services Standards, Semantic Web Technologies	Out-Of-Scope Addressing issues specific to e-market place are beyond the scope of this work. However, the prototype will rely on open-standards technologies, which will help in the e-market vision realisation.
Nd. 4.	Need to automate supply chain processes	There is a need to remove inefficiencies from the supply chain, by automating various processes.	Web Services, Wireless communication, Tagging Technologies	In-Scope Some of the issues related to automated information flow across the supply-

¹⁶ Abbreviation of Need

No.	User Need	Rationale	Techniques & Technologies	In-Scope/Out-of-Scope
Nd. 5.	Need to address security concerns in Mobile Application Development	Trust is a major issue in mobile application deployment. Transmitting corporate data over the wireless link may expose the entire network to hackers.	Wireless Security Technologies	<p>chain will be addressed.</p> <p>Out-Of-Scope The prototype will provide basic authentication mechanism. However, addressing specific security issues is beyond the scope of this work.</p>
Nd. 6.	Need for dynamic generation of content	In case where information is not readily available, it will be useful to have dynamic content generation, to respond precisely to the user queries	Semantic Web (by better awareness of the semantics of the document contents)	<p>Out-Of-Scope On-the-fly content generation based on the user context is difficult to implement because of the complexities of the technologies involved. Also, some of the enabling technologies are not mature enough.</p>
Nd. 7.	Need for innovative ways to address limited interface of mobile devices to enhance usability.	As a mobile worker is engaged in many tasks on-site, the system should be easy to learn and use. It should have a clear and straightforward interface.	Multi-modal interfaces (VoiceXML, Handwriting Recognition)	<p>Out-Of-Scope Prototype implementation will rely on the principles of effective human interface design, and its usability features will be evaluated.</p>
Nd. 8.	Need for access to real time project data.	Need to provide construction teams access to real time data and the ability to review and update project management plans.	Wireless Project Management	<p>In-Scope Prototype implementation will address the key issue of providing project</p>

No.	User Need	Rationale	Techniques & Technologies	In-Scope/Out-of-Scope
				management support to users.
Nd. 9.	Need for using tagged information in all phases of the project lifecycle	Information about construction components can be stored in tags, which can be intelligently queried through all phases of the project lifecycle.	Tagging technologies	In-Scope Prototype implementation will address some of the related issues.
Nd. 10.	Need to bring intelligence on-site	Creation of an intelligent environment, which has the ability to proactively understand and proactively respond to the user needs is important.	Tagging technology, Context-awareness	In-Scope Some of the issues will be addressed in the implementation.
Nd. 11.	Need to enhance interoperability and application integration	Need to enhance interoperability across the supply chain. Currently, the level of interoperability, as envisaged in the scenarios, does not exist. Moreover, there is need for scalable applications, that can be iteratively improved.	Web Services, Ontologies for data exchange, Application Integration Technologies	In-Scope Prototype will rely on the use of open standards and technologies for application integration.
Nd. 12.	Need for communication support infrastructure	There is a need to enhance communication at an intra-site level, by allowing site-workers to engage in real time voice or video conversations.	Real Time Voice communication, paging, video transmission	In-Scope Implementation will address the need for real time connectivity.
Nd. 13.	Need to automate various manual and paper-based tasks	Current paper-based procedures are cumbersome and time-consuming. These can easily be automated using mobile technologies.	Mobile application development technologies	In-Scope Implementation will address some of the task automation needs
Nd. 14.	Need for tangible benefits and cost reduction	It is imperative that the proposed technologies bring tangible benefits like enhanced productivity with the promise of cost reduction.	Technologies with maximum cost benefit potential.	In-Scope Implementation will keep this need in perspective.

The user needs hierarchy (Figure 6-1) classifies the needs (both In-Scope and Out-of-Scope) in four different categories namely real time communication, inventory logistics, ubiquitous intelligence, and technology application.

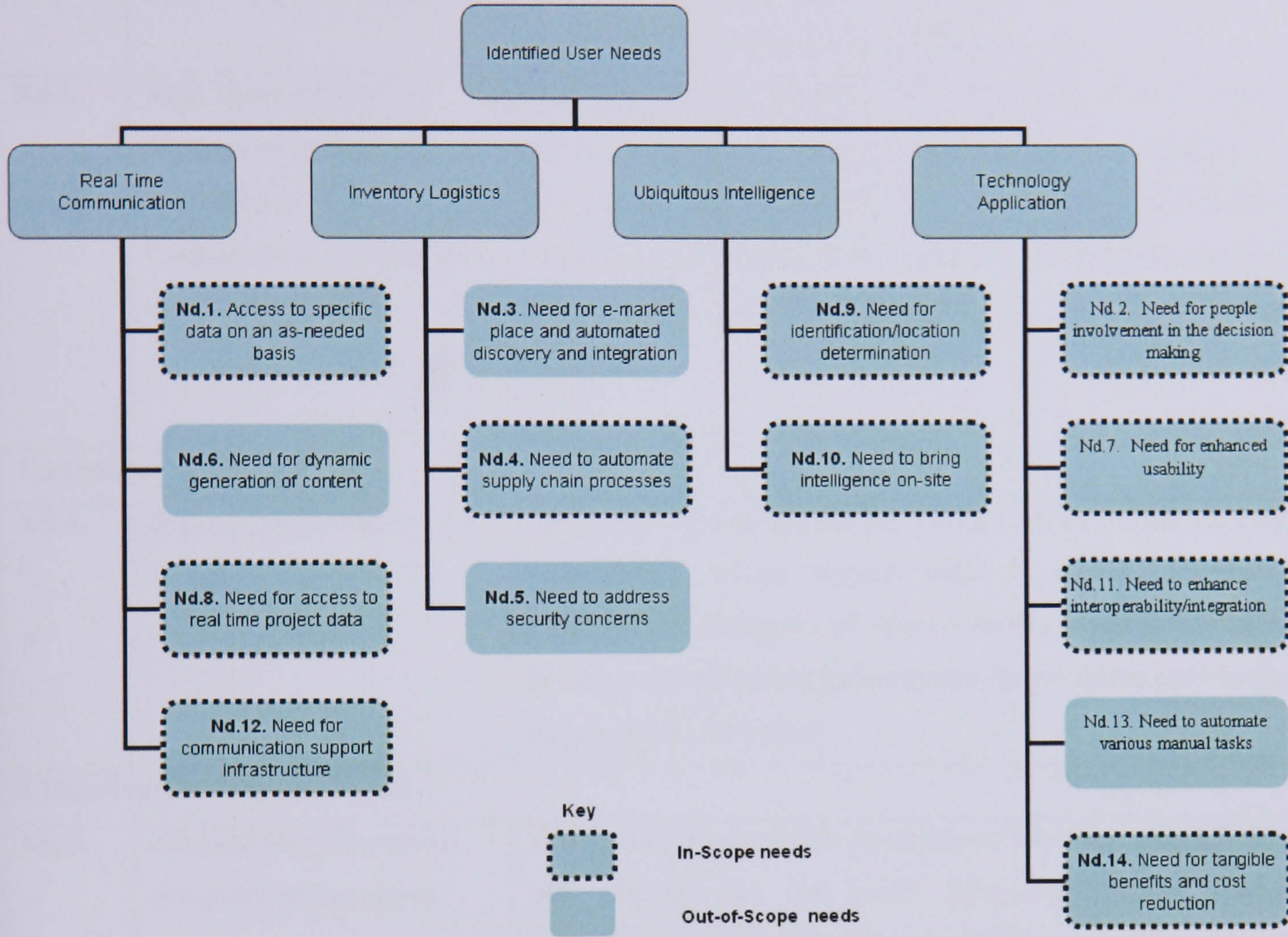


Figure 6-1: User Needs Hierarchy

6.3. System Design Goals

In this section, the needs hierarchy is used to define the system design goals. These goals were intended to guide the development and the evaluation of the prototype. The left column in Table 6-2 associates the user needs (as described in Figure 6-2) to design goals.

Table 6-2: System Design Goals

No.	Design Goal	Description
Real-Time Communication Needs		
Nd.1.	Access to Highly Specific Data On As-Needed Basis	The system should be smart enough to understand the worker's context, and to deliver data to him/her based on the context, thereby preventing information overload.
Nd.8.	Real Time Project Management Support	The system should provide users an ability to view project management plans/schedules, and update them in real time.
Nd.12	Provision of Communication Support for mobile workers	The system should address the user's need for real-time communication support. This includes communication support such as video, voice and paging, for both intra-site and inter-site staff.
Inventory-Logistics Needs		
Nd.4.	Process Automation Needs	The system should reduce the work load of on-site staff by automating various manual tasks. It should specifically address the automation of various supply chain tasks. Also, the issue of automating various paper-based forms used on the site should be addressed.
Ubiquitous Intelligence Needs		
Nd.9.	Identification/Location determination support	The system must provide an ability to identify different users and objects. At the same time, real time location determination support must be provided.
Nd.10.	Ubiquitous Intelligence Support	The system should provide ubiquitous intelligence support to mobile workers by bridging the gap between the physical world of construction operations and the virtual world of computers through technologies such as radio frequency identification (RFID), location-based computing, context-awareness, etc.
Needs related to Technology Application		
Nd.2.	Need to support the decision making process	The system should not take key decisions on behalf of human users. However, it should support the decision making process, by delivering relevant information to the users.
Nd.7.	Usability	Keeping in view the small display size, limited input/output capabilities and other energy and safety requirements of mobile devices, the system should be usable in a construction site environment. It should be easy to use and learn, and offer a very clear and straightforward interface.

No.	Design Goal	Description
Nd.11	Need to address interoperability/ Integration/ Scalability & Flexibility	Rather than building another island of automation, the system should build on existing technologies. Technology used should be interoperable and integrate well with the existing systems used in the construction industry. To achieve this goal, it is important to adhere to open standards and technologies and construction industry standards. Also, the system should be scalable, so that it can be iteratively improved.
Nd. 14.	Tangible Benefits and Cost Reduction	For the construction industry to seriously consider any new technology, it is important that the system offers tangible benefits with the promise of cost reduction.

6.4. Implementation Scenario

This section describes the scenario, which has guided the development of the proposed architecture and the subsequent implementation. During the illustration of potential deployment scenarios and subsequent interview discussions (Chapter 5), a set of vertical applications for the construction industry were identified (as discussed in Table 5-2). These applications were included in the implementation scenario and are presented as a day in the life of a construction site personnel. Key elements of the scenario are illustrated in Figure 6-2 and are discussed below:

- 1. Profile Based Task Allocation:** After a successful log-in, based on the site personnel's profile, relevant services are made available as icons on the mobile-worker's mobile device. Clicking on the task-list icon, the mobile worker can see the list of tasks to be performed and an associated method statement illustrating the method that needs to be followed. Completion of tasks is monitored in real time and is recorded in the project management application. An audit trail is maintained of the tasks allocated and recorded completion. This allows the project manager to monitor the current status of the project and tasks.

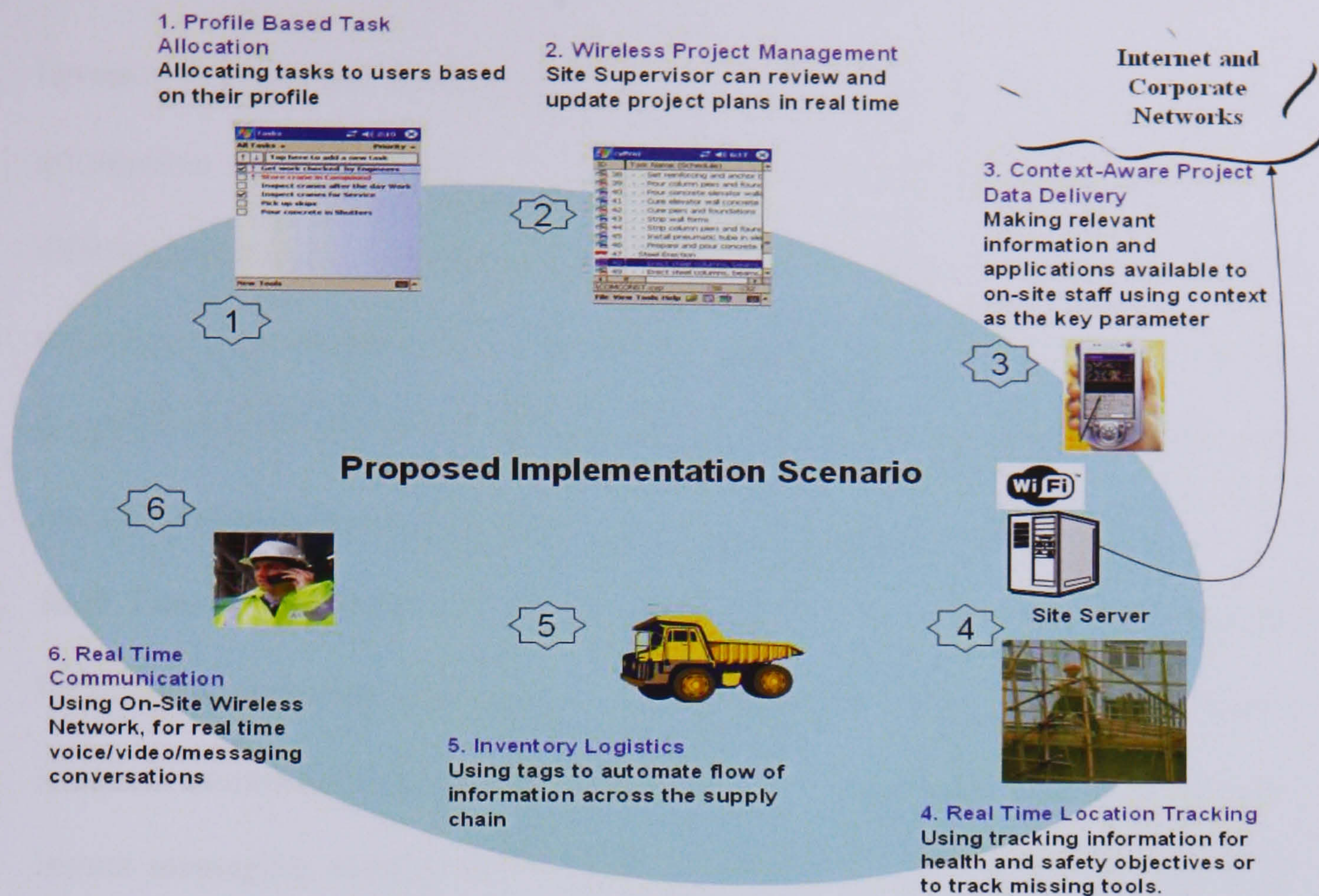


Figure 6-2: Implementation Scenario

2. **Wireless Project Management:** The mobile worker can view the project management plan and progress on various tasks and sub-tasks and can update project plans in real-time.
3. **Context-aware Project Data Delivery:** Application and data provision to users are linked to their existing context (i.e. Personal profile, task at hand, location etc.). As the user context changes (e.g. change of location, change of task, etc.), data related to the existing context is made available.
4. **Real Time Location Tracking:** As the worker moves across the construction site, his/her location details are updated on the corresponding site map. Real time positioning of all site operatives is recorded for Health and Safety objectives. At the same time, construction equipment, materials and other high value construction assets are tracked. This allows for keeping track of inventory items.

5. **Inventory Logistics:** Inventory items are tagged. Each tag contains important information about the object it is attached to. This allows the tag to be queried at different points across the supply chain. As the delivery arrives at the site, the site supervisor gets a message on his/her mobile device. The site supervisor can check the delivery contents and can record discrepancies, if any. Confirmation of delivery receipt is recorded in real-time in the inventory database.
6. **Real Time Communication:** Mobile workers use the existing wireless network for real time communication with on-site and off-site colleagues. Depending on the situation, communication may be voice based (e.g. voice calling), data based (e.g. instant messaging, sending photographs and files) or a combination of both (e.g. video conferencing).

Based on the aforementioned scenario description, the prototype will satisfy the information needs of the mobile worker, as shown in Table 6-3.

Table 6-3: Information needs of the user by category and sub-category

Information Category	Information Subcategory
Wireless Project Management / Profile Based Task Allocation	<ul style="list-style-type: none"> Ability to update tasks and resources in real time through a mobile device. Allocation of tasks and method statements to users based on their profile and existing context.
Context-Aware Project Data Access	<ul style="list-style-type: none"> Making project information available to users based on their existing context (e.g. location, time, task, profile etc).
Real Time Tracking	<ul style="list-style-type: none"> Ability to track real time location of a person or an object.
Inventory Logistics	<ul style="list-style-type: none"> Using tags to automate the information flow across the supply chain.
Real Time Communication	<ul style="list-style-type: none"> Using on-site wireless network for real time voice/video/messaging conversations.

6.5. System Design Choices

This section evaluates various alternatives available for the prototype design and implementation.

6.5.1. Choice of the Development Environment

Two main environments were considered for the mobile application development. This included Sun Micro-system's Java 2 Micro Edition (J2ME) and Microsoft's VisualStudio.NET environment. In the final analysis, the Microsoft's VisualStudio.net development environment was chosen for the following reasons:

1. Firstly, the visual interface of the VisualStudio.net environment provides the development efficiency, allowing for rapid prototyping. Its drag and drop development environment (Fig 6-3) provides a higher level of abstraction to the programmer, making the programming tasks relatively easier. In contrast, J2ME approach involves a lot of coding even to accomplish simple tasks.
2. Secondly, VisualStudio.net programming approach is based on existing desktop-based development languages (e.g. Visual-Basic and C-Sharp). In contrast, the J2ME approach to mobile development involves learning a new set of tools. Based on previous experience of the Microsoft development environment, Microsoft tools were used for the prototype development.

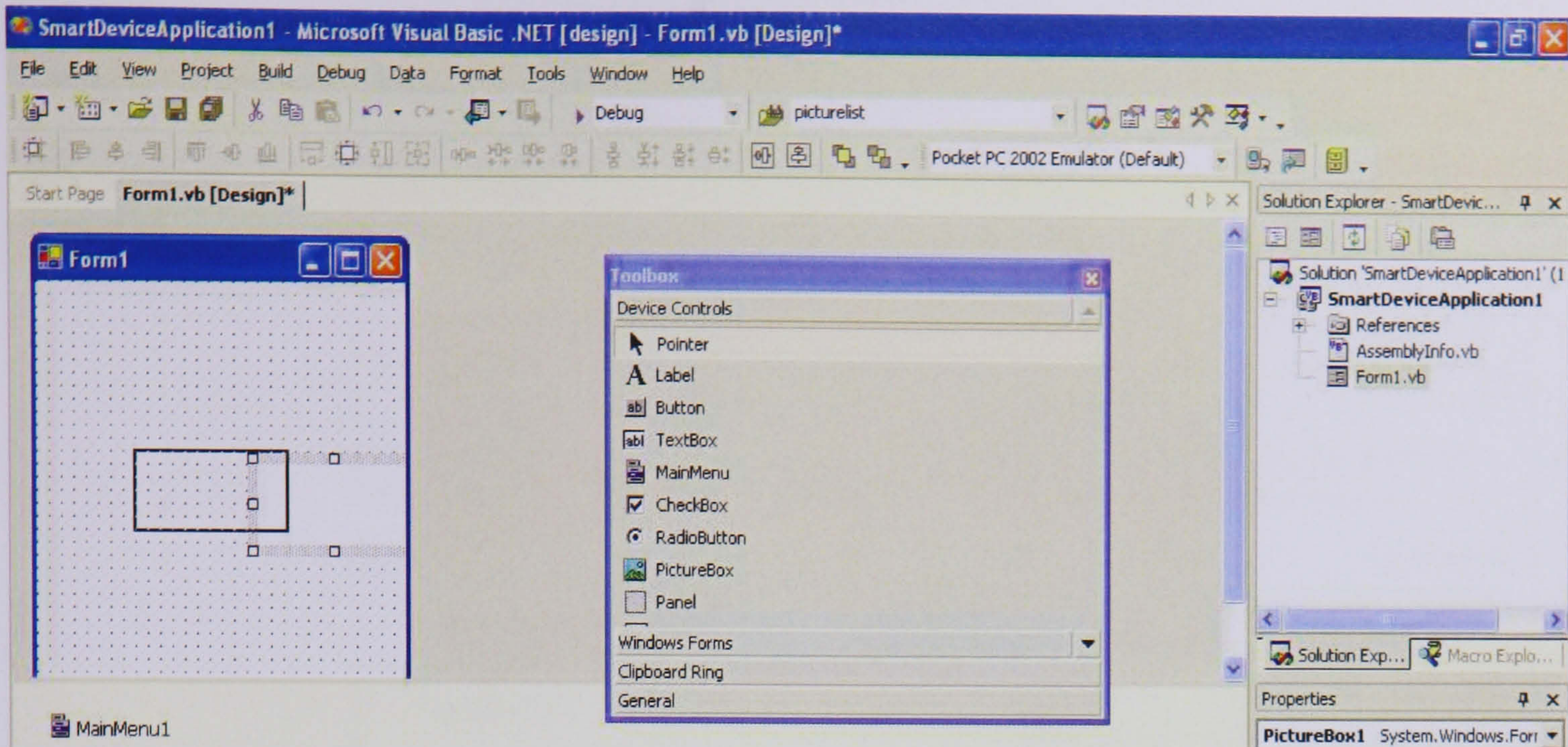
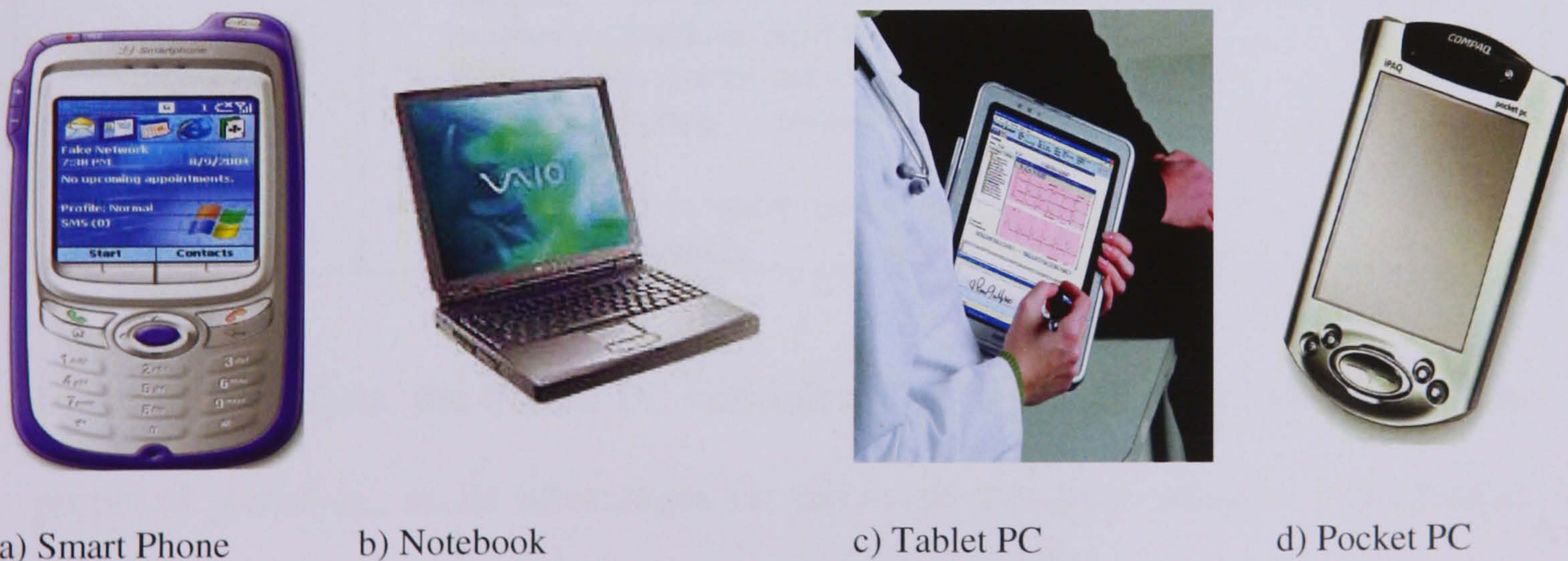


Figure 6-3: Visual-Studio.net Environment

6.5.2. Choice of the Mobile Development Platform

Four different development platforms that can possibly be used by mobile-worker were tested to identify the optimal hardware for the prototype deployment (Figure 6-4). Testing of the notebook and Pocket-PC were done on actual hardware platforms, whilst a software emulator was used for testing the smart-phone and Tablet-PC. The relative advantages and disadvantages are summarised in Table 6-4.



a) Smart Phone

b) Notebook

c) Tablet PC

d) Pocket PC

Figure 6-4: Platforms investigated for Mobile Application Deployment

Table 6-4: Relative advantages and disadvantages of different

Development Platform	Advantages	Disadvantages
Smart-Phone	<ul style="list-style-type: none"> • Lowest cost compared to other platforms • Provide full time connectivity, including SMS support • Support for the Internet standards • Many smart-phones contain in-built cameras • Smallest of compared platforms 	<ul style="list-style-type: none"> • Relatively small interface • Lack of Touch screen capability, means that input can only be through small phone buttons • Difficult to handle various controls • Lack of support for WLAN • Little support for application development provided by existing telecom operators • Optimised for voice traffic and only limited support for data access • Very low in memory, storage and processing power. Thus it is difficult to migrate desktop based applications to smart-phone platform
Notebook	<ul style="list-style-type: none"> • Used extensively in office-based environments • Most notebooks have Bluetooth/WLAN capabilities • Powerful processors 	<ul style="list-style-type: none"> • Lack of Touch Screen • Size is difficult to handle for day to day construction operations • Difficulty in reading the laptop screen outdoors • Harsh site environments may damage the notebook computer
Tablet PC	<ul style="list-style-type: none"> • Touch screen • Easy to handle compared to notebook 	<ul style="list-style-type: none"> • Very expensive compared to other development platforms • Size of the tablet PC makes it quite inconvenient for day to day on-site usage
Pocket PC	<ul style="list-style-type: none"> • Touch Screen • Very convenient size i.e. easily fits into pocket • Supports standard Web browsers, capable of handling HTML. Thus can be used to access existing project extranets • Can be used to serve both voice and data needs 	<ul style="list-style-type: none"> • Processing power remains limited compared to other platforms like notebooks and tablet PC • Limited memory and display size

In the final analysis, the Pocket PC was selected as a development platform for the proposed prototype, as its advantages far outweigh the disadvantages. Two Pocket PCs (Dell Axim) and HP IPAQ 5550 were used to implement and test the prototype.

6.5.3. Choice of Wireless Network and Technology

In the WiSeCon framework (Section 3.5.2), wireless technologies provide a vital link between the wireless front end and the wired backbone. For the prototype implementation, both wireless wide area networking technologies (e.g. GSM, GPRS, UMTS/3G) and wireless local area networking technologies (e.g. Bluetooth and WLAN) were considered. Wireless Wide Area Networking technologies did not satisfy the design criteria for the following reasons:

1. **Availability of little integration support:** Currently, most network operators do not provide an open interface architecture. Infrastructure for deployment and piloting applications is not available. Without the availability of such piloting support, it is difficult to develop applications which integrate well with existing construction information systems.
2. **Expensive to implement and maintain:** Most network operators will charge a premium for using their infrastructure for delivering applications. This is not the case with WLAN/Bluetooth technologies, where the organisation owns the infrastructure.
3. **Limited Bandwidth:** Maximum theoretical bandwidth for GPRS network is 171.2 Kilo bits per second whereas a 3G network has the maximum potential of 2 Mega bits per second data transmission for fixed indoor connections (Olexa, 2005). In comparison, WLAN (IEEE 802.11g standard) supports a theoretical bandwidth of 54 Mega-bits/second.
4. **Multiple Standards:** Multiple standards for wireless wide area networking technologies are currently in use (e.g. GSM, GPRS, EDGE, UMTS). These different standards prevent the deployment of flexible construction applications.

In the prototype implementation, W-LAN technology is used for network access. It is also used for providing voice and real-time tracking support. Bluetooth wireless technology was used to synchronise data between the mobile device and the server application.

6.6. The Physical Architecture

Based on the WiSeCon framework (Section 3.5.2) and the system design choices as discussed in section 6.5, this section presents the system architecture (Figure 6-5). The architecture is based on multiple tiers which are explained below:

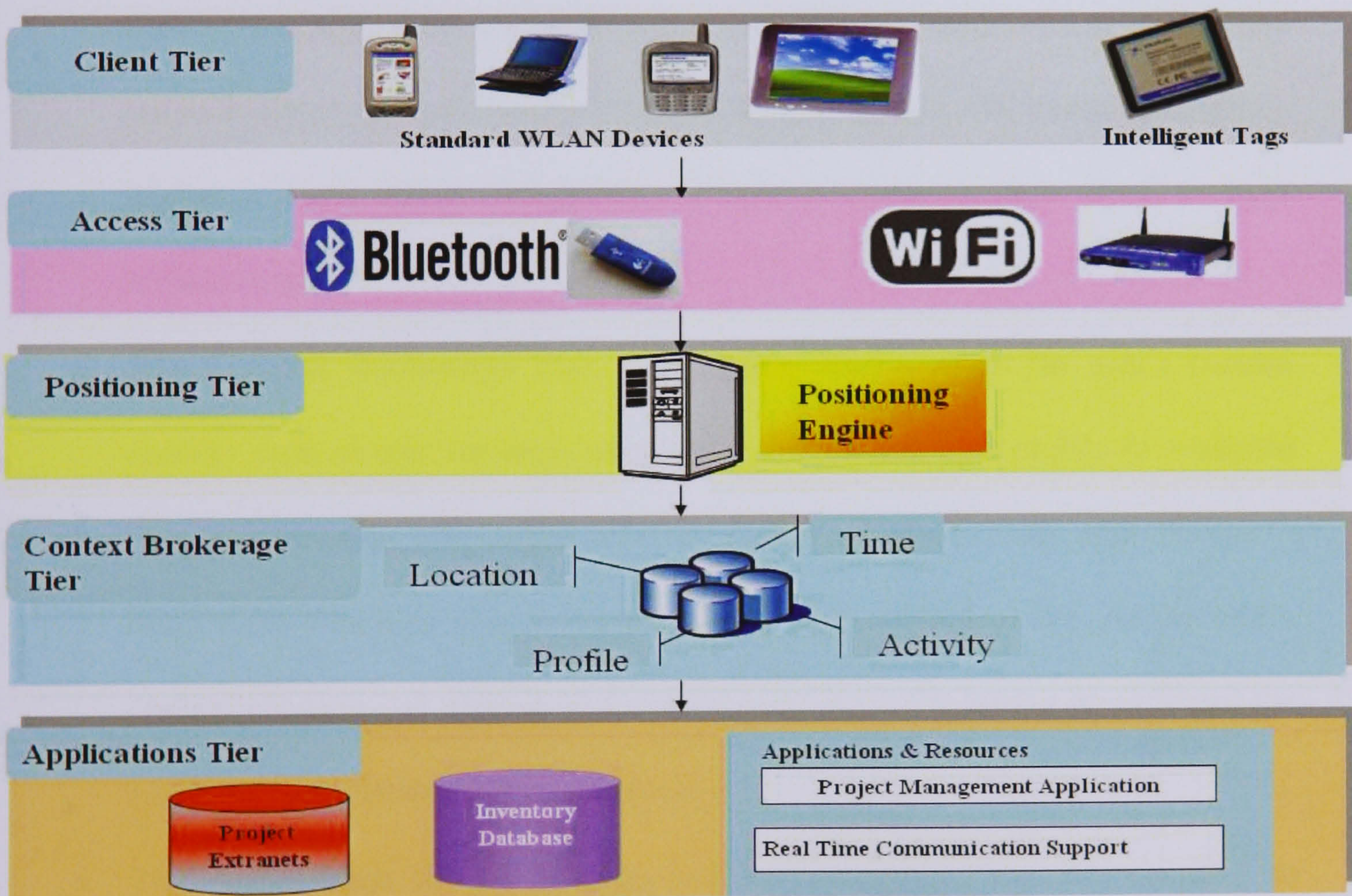


Figure 6-5: Physical Architecture

- **The client tier:** This tier provides users with access to the system. It supports standard W-LAN enabled devices and intelligent tags. Intelligent tags contain

vital information about the objects they are attached to and are tracked through a positioning engine.

- **The Access tier:** It provides the vital communication link between the wireless front end and wired back bone. Wireless LAN (or WiFi) technology is used to provide network access, while Bluetooth is used to synchronises data on the mobile workers' device and the site server. The access tier supports both push and pull modes of interaction (i.e. information can be pushed to the user, or the mobile worker can pull information through ad-hoc requests).
- **The Positioning Tier:** The positioning engine tracks mobile devices through their unique IP address and determines their real-time location. Location of the tracked object is updated at regular intervals. A W-LAN based positioning engine is used, which determines real-time position through signal-strength measurements.
- **The Context Brokerage Tier:** The context broker maps the user's current context such as user location, user activity, time and user profile to available data and services. The output from the broker is then fed into applications to make them aware of what is happening on the construction site. As the user's context changes (i.e. change of location, tasks etc.), the broker recalculates the available services to users in real time.
- **The Application tier:** It contains construction applications and services, to support mobile workers. As logic and data processing resides on the wired network, the mobile client is charged with minimal memory and processor-consuming tasks.

6.7. The System Model

The system model consists of six different sub-systems, representing the different functionality offered by the system (Fig 6-6). The prototype was designed and implemented as individual sub-systems so that each sub-system can be implemented, tested, and changed independently of each another. This is essential to achieve the design goal of scalability and flexibility. Each system component can be completely changed with no impact on the rest of the system.

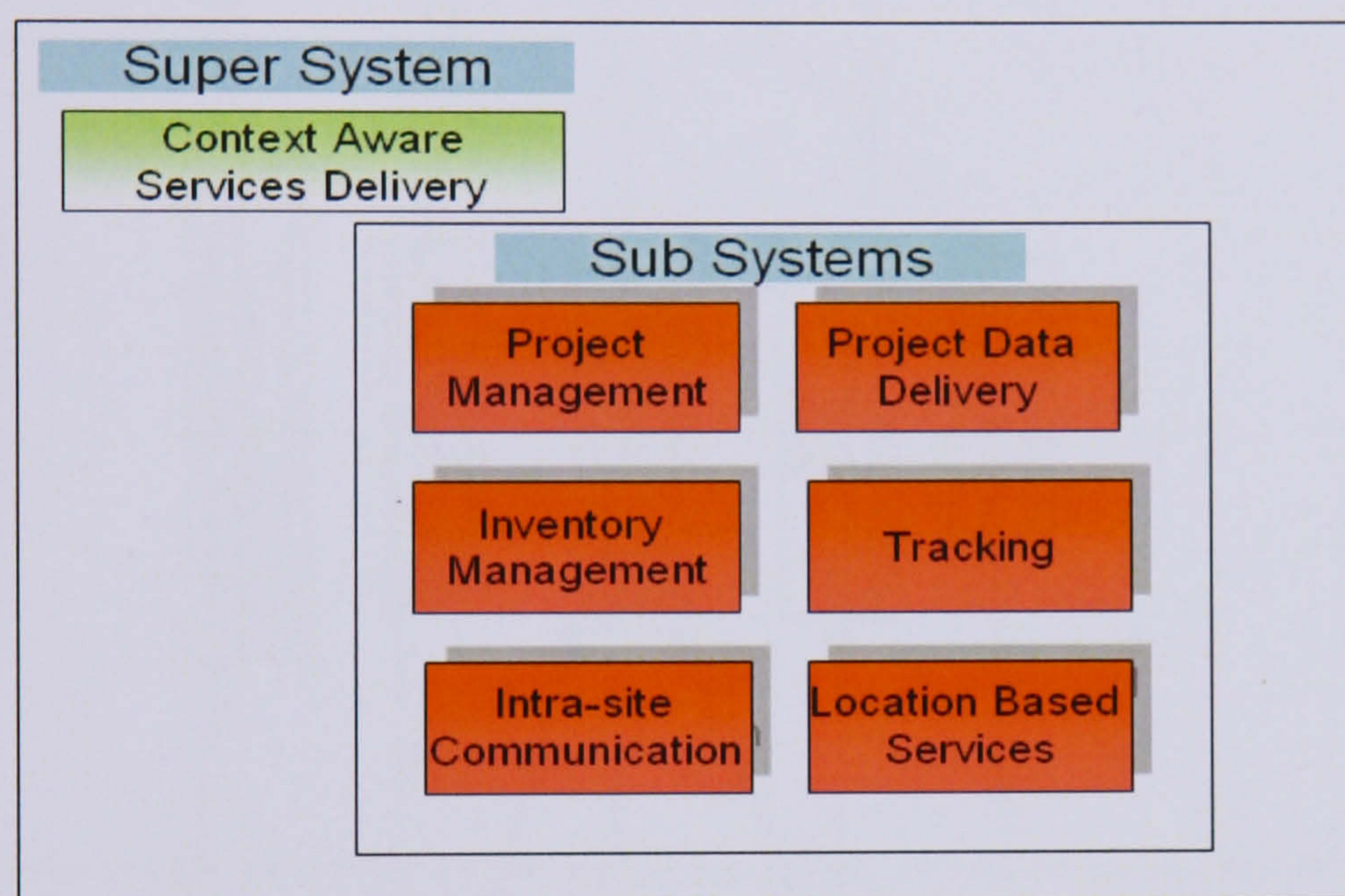


Figure 6-6: System Model

Figure 6-7 shows the application architecture, illustrating how system activities are carried out. After a successful log-in, the mobile worker is able to see a set of services. These services could be accessed on an as-needed basis. The system activities are explained in more detail in the use-case analysis section (Section 6.8).

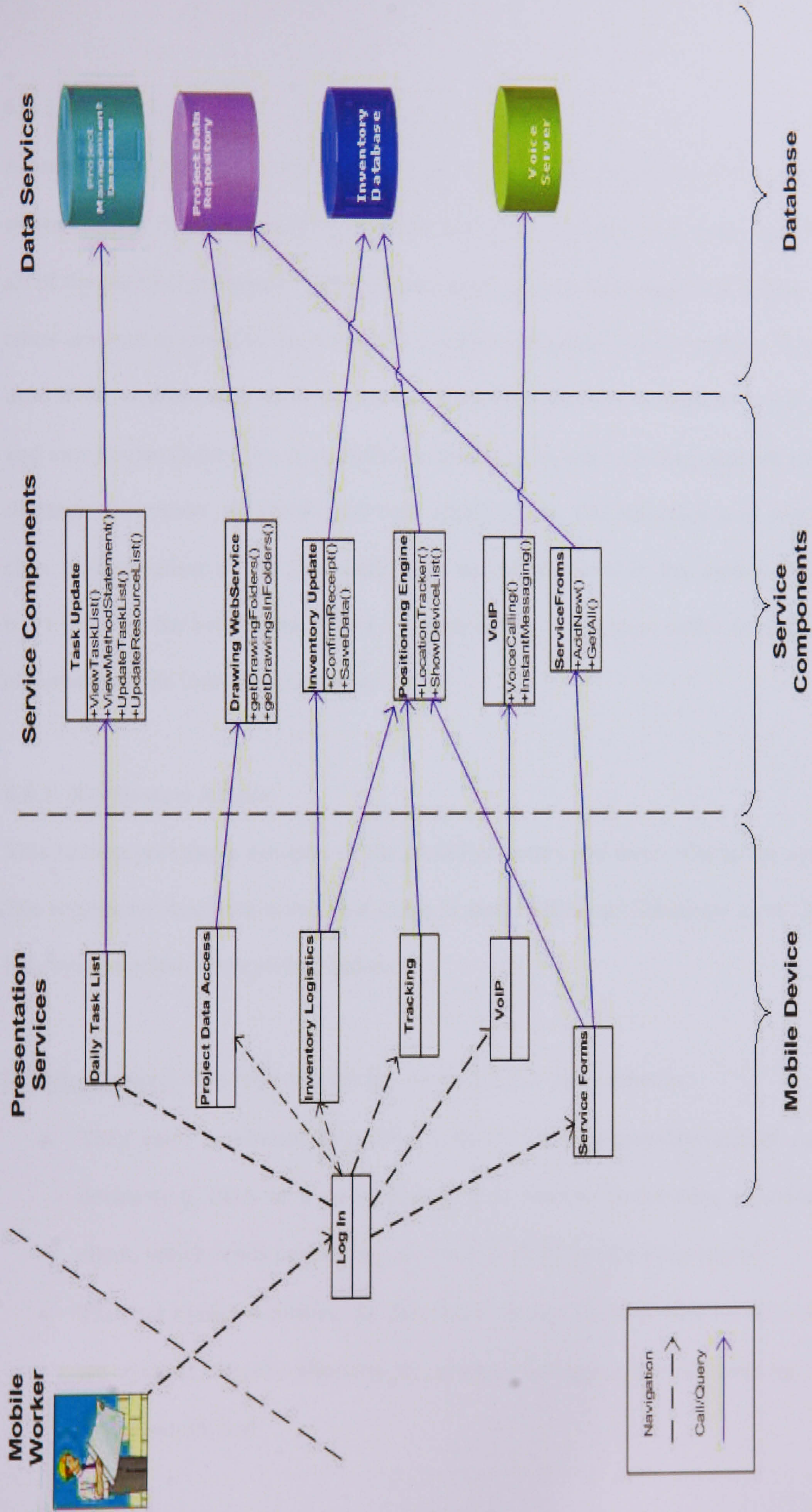


Figure 6-7: Application Architecture

6.8. Use-case Analysis

A use-case is a functional requirement described from the perspective of the users of a system (Alhir, 2003). The objective of the use-case analysis is to identify and define all of the business processes that the system must support (Stazinger et al, 2004). Use-cases are used to describe the outwardly visible requirements of the system. They are used in the requirements analysis phase of the project and also contribute to test plans and user guides (Schneider et al, 2001). In this section, use-case diagrams are used to illustrate the system, the actors, and their relationships. The objective is to provide a clear understanding of the functionality to be implemented in the system. Section 6.8.1 explains the key system actors and their role in the system while Section 6.8.2 elaborates on the individual use-cases.

6.8.1. Key System Actors

This section provides a synopsis of the identified actors and their roles in the system. The term actor describes a unit that helps in task fulfilment (Schneider et al, 2001). Key system actors are described below:

Mobile Worker: This type of actor has the following characteristics:

- They carry a wireless (e.g. Bluetooth/WLAN) connectivity-enabled mobile device (e.g. PDA or a smart phone). The mobile device runs a positioning client, which sends positioning information to the positioning engine;
- They are dynamic entities. As they move around the site, their location details are updated, thereby allowing the positioning engine to determine their real time location; and

- They can use applications and services relevant to their context, through a client application.

Positioning Engine (PE): In the system design, the PE essentially performs two functions. Firstly, it discovers all devices within a wireless domain, Secondly, it tracks the current location of each device.

Tagged Equipment: Tagged equipment represents an object whose position is being monitored in real time by the positioning engine.

Context Broker: The context broker interprets the current context of the user and matches it to the list of available services. The interpretation of the user context and service determination is a dynamic process, which takes place at regular time intervals.

Site Server: The site server communicates with the mobile client and provides network access to the mobile client.

Push Server: The push server is responsible for pushing messages and information from the site server to the user's mobile device.

Using the above key actors, the principal use-cases developed for the prototype system are presented in the following sub-sections. Each use-case starts with a brief description, which is followed by a summary of pre-conditions (i.e. the conditions that must be fulfilled before the use-case will begin), the flow of events (including the basic

path and the alternative paths) and an activity diagram (which describes user activities and their sequence).

6.8.2. Use-Case: Log-In

This use-case (Figure 6-8) describes the process by which the user logs in to the system. It also sets up the access permissions for the various categories of users.

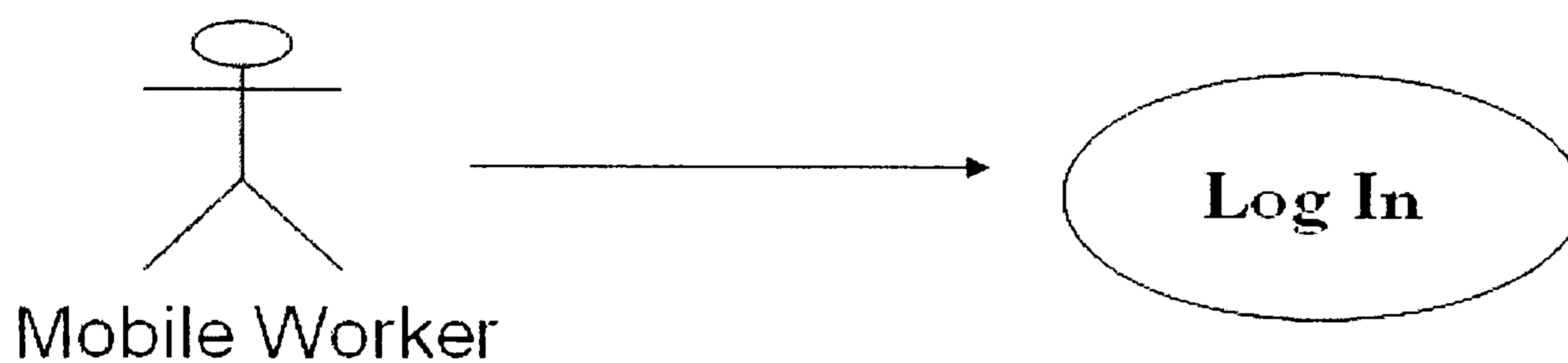


Figure 6-8: Log-In Use-case

Pre-Conditions

- The user is carrying a mobile device (e.g. PDA, Tablet PC, etc);
- The user is within range of an on-site wireless network; and
- The user's IP address and access permissions are registered with the server.

Flow of Events

Basic Path

1. This use-case begins when the user enters an on-site wireless network.
2. The system detects the user, from the unique address of his/her mobile device.
3. The system pushes an instant message, prompting the user to log in.
4. If the user decides to log in

- a. The system displays the Login screen.
 - b. The user enters a username and password.
 - c. The system verifies the username and password.
 - d. If the log-in is successful, the system records the log-in details for payroll and health and safety objectives.
 - e. The system determines the list of available services based on the user context and profile.
 - f. The list of available services appears as icons on the user device.
5. The use-case ends

Alternative Paths

- If the username or password is incorrect, Log-In fails.
- The user does not want to log-in, and closes the application.

Activity Diagram

Figure 6-9 shows an activity diagram. An activity diagram is a type of workflow diagram that describes the user's activities and their sequence (Stazinger et al, 2004).

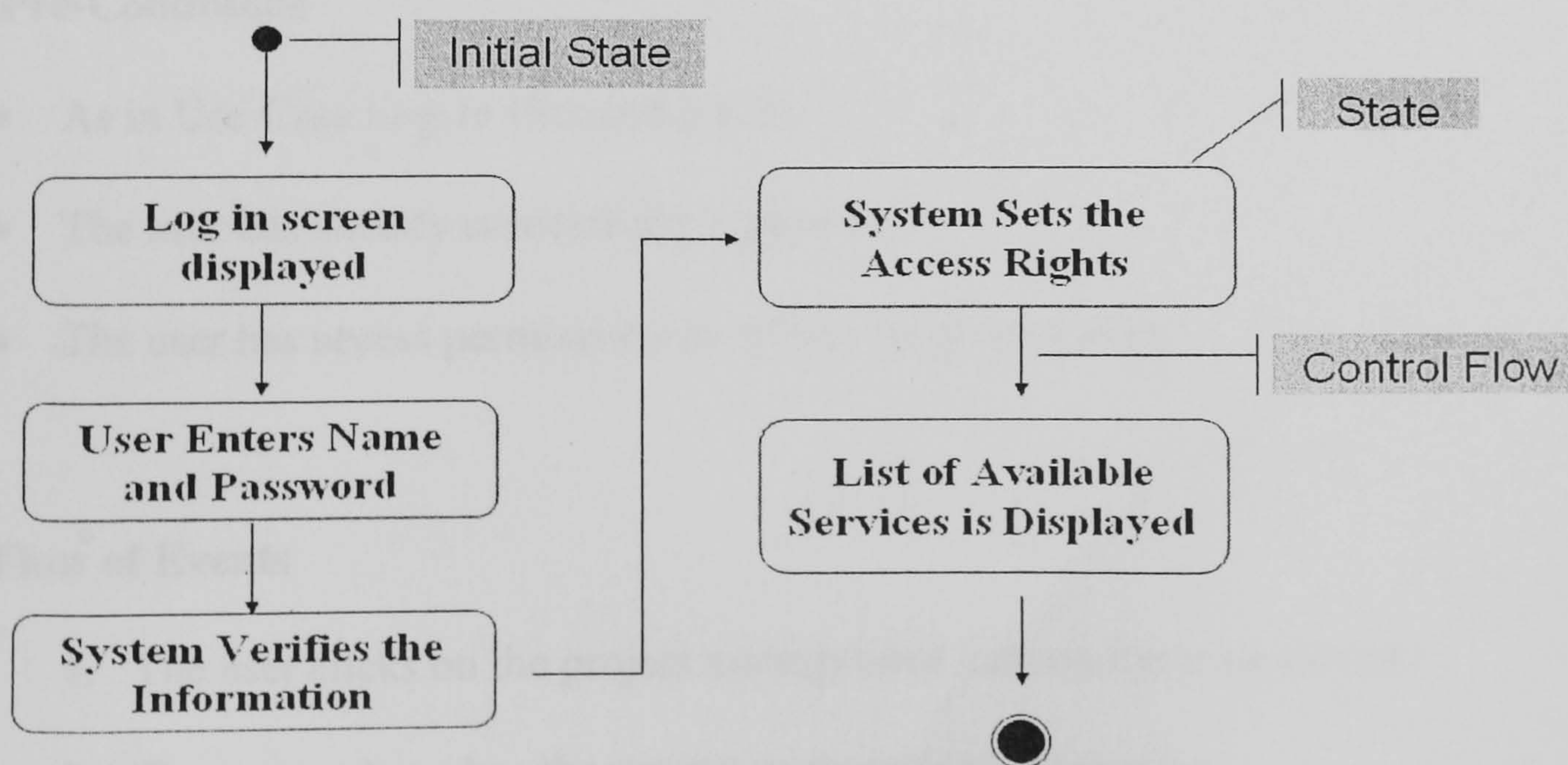


Figure 6-9: Activity Diagram – Log- In Use-Case

6.8.3. Use-Case: Task Allocation And Wireless Project Management

This use-case describes the process (Fig 6-10) by which the mobile worker can review his/her daily task list, review the method statement (the method statement contains details such as the sequence of work to be undertaken, equipment, permits, labour force, risk assessment associated with the task list), update the project plan and update the resources associated with a task.

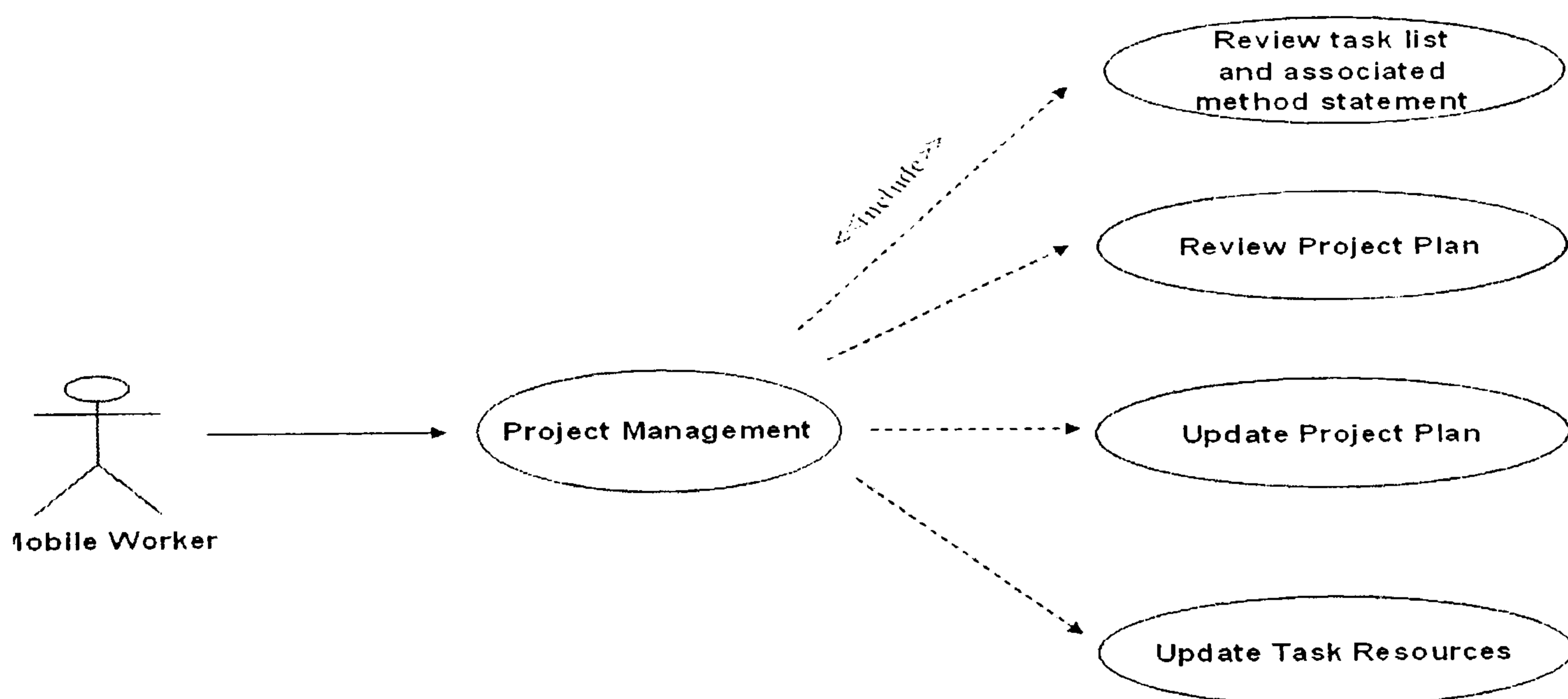


Figure 6-10: Task allocation and Wireless Project Management Use-Case

Pre-Conditions

- As in Use-Case Log-In (Section 6.8.2).
- The user has already successfully logged-in.
- The user has access permissions to update the project plan.

Flow of Events

1. The user clicks on the project management icon on the main screen.
2. The system launches the project management application.
3. The user reviews his/her daily task list, on the mobile device.

4. The user reviews the method statement associated with a particular task list.
5. The user can update the progress on a particular task.
6. The user can record any changes in the project plan.
7. The user can change the resources assigned to a particular task.
8. System records the changes in real time in the back end system.

Activity Diagram

The synchronisation bar in the Figure 6-11 is an activity diagram symbol to control the splitting or uniting of the sequential paths.

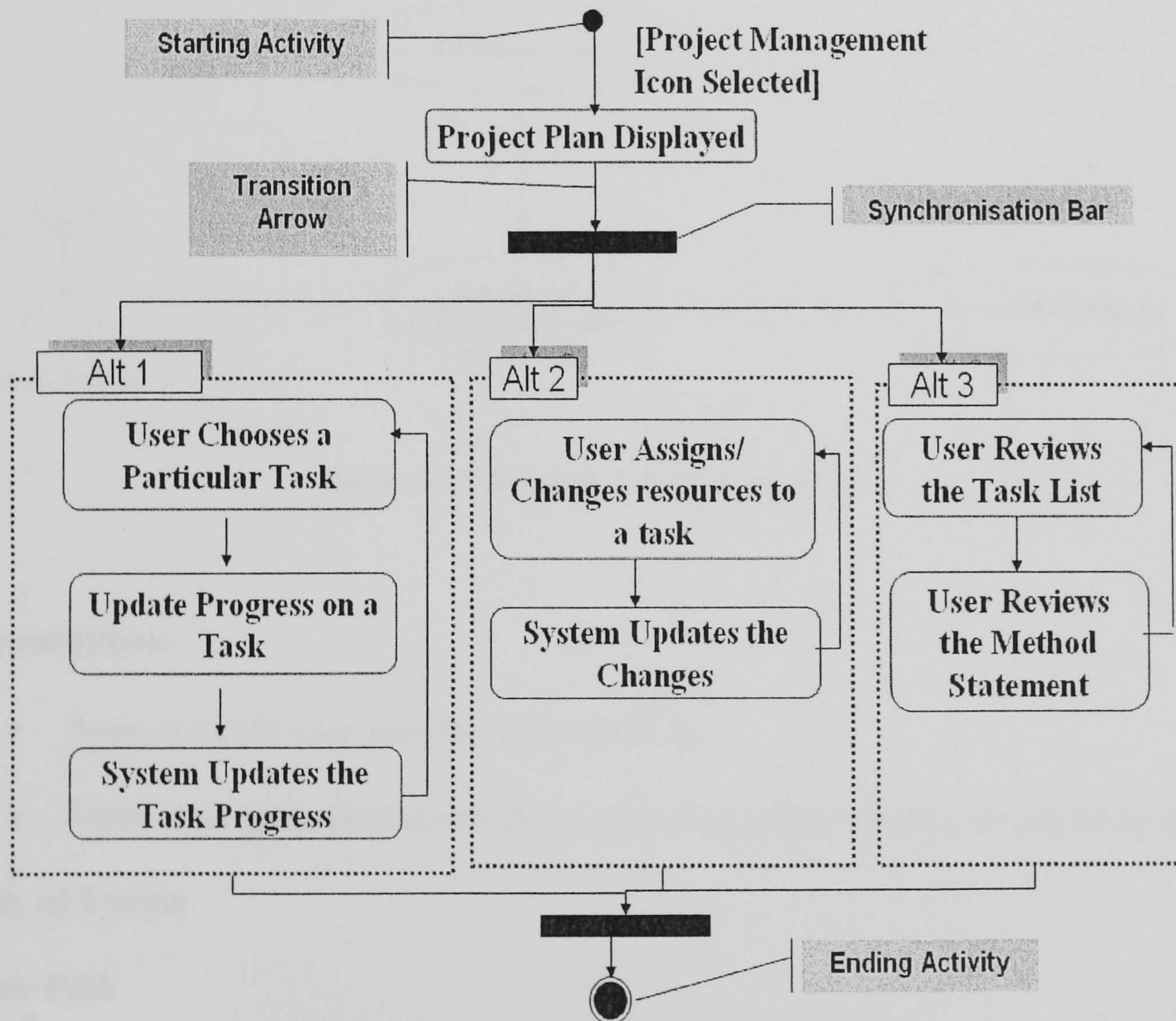


Figure 6-11: Activity Diagram- Project Task Update

6.8.4. Use-Case: Inventory Logistics

This use-case describes the process (Figure 6-12) by which intelligent tags are used to automate the information flow across the supply chain. In this use-case, the supplier records relevant order, product and supplier details on the tag before dispatching it. The tag can be queried at any point in the supply chain. As the delivery arrives on-site, data from the tag is passed to the supervisors' mobile device. Receipt of the order is confirmed by the site supervisor and any discrepancies are recorded. Figure 6-13 presents the activity diagram showing the sequence of activities.

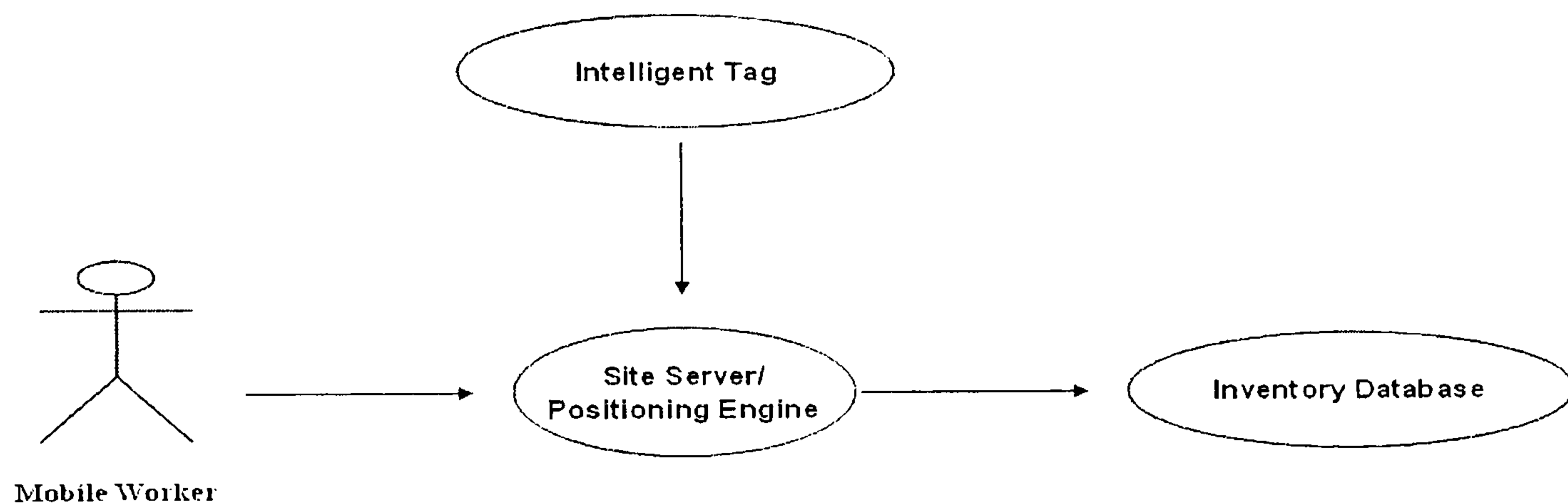


Figure 6-12: Inventory Logistics Use-Case

Preconditions

- Same as in use-case Log-In (Section 6.8.2).
- There is an agreement across the supply chain about the data stored on the tag.

Flow of Events

Basic Path

1. The use-case begins when the supplier receives a new order.
2. The supplier prepares the order.
3. The supplier stores the relevant order details (i.e. order details, product details, supplier details) on the intelligent tag.

4. Logistics collect and deliver the tag to the site.
5. As the delivery arrives on-site, information from the tag is passed to the site supervisor's mobile device.
6. The site supervisor confirms the receipt of the order.
7. Confirmation is recorded in real-time in the inventory database.

Alternative Paths

- The site supervisor records any discrepancy in the delivery.
- The site supervisor cancels the order and returns delivery (Precondition: Delivery receipt is not confirmed).

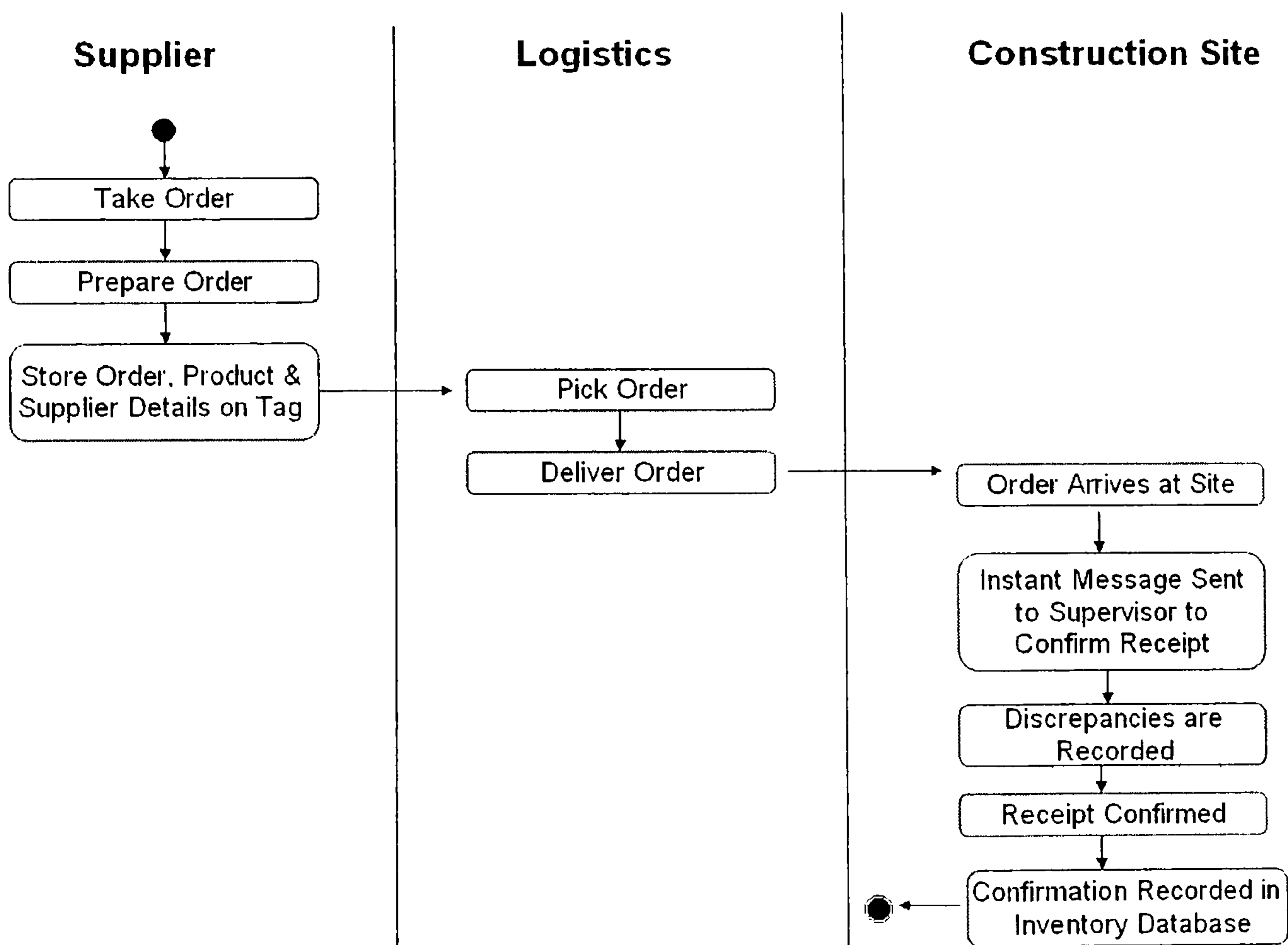


Figure 6-13: Inventory Logistics Activity Diagram

6.8.5. Context-aware Project Data Access Use-Case

This use-case (Fig 6-14) describes the process by which a mobile worker can access project information based on his/her context (i.e. location, time, profile, assigned task, etc). In this use-case, the context broker plays the key role of capturing the user context and mapping the user context to project data, at regular time intervals.

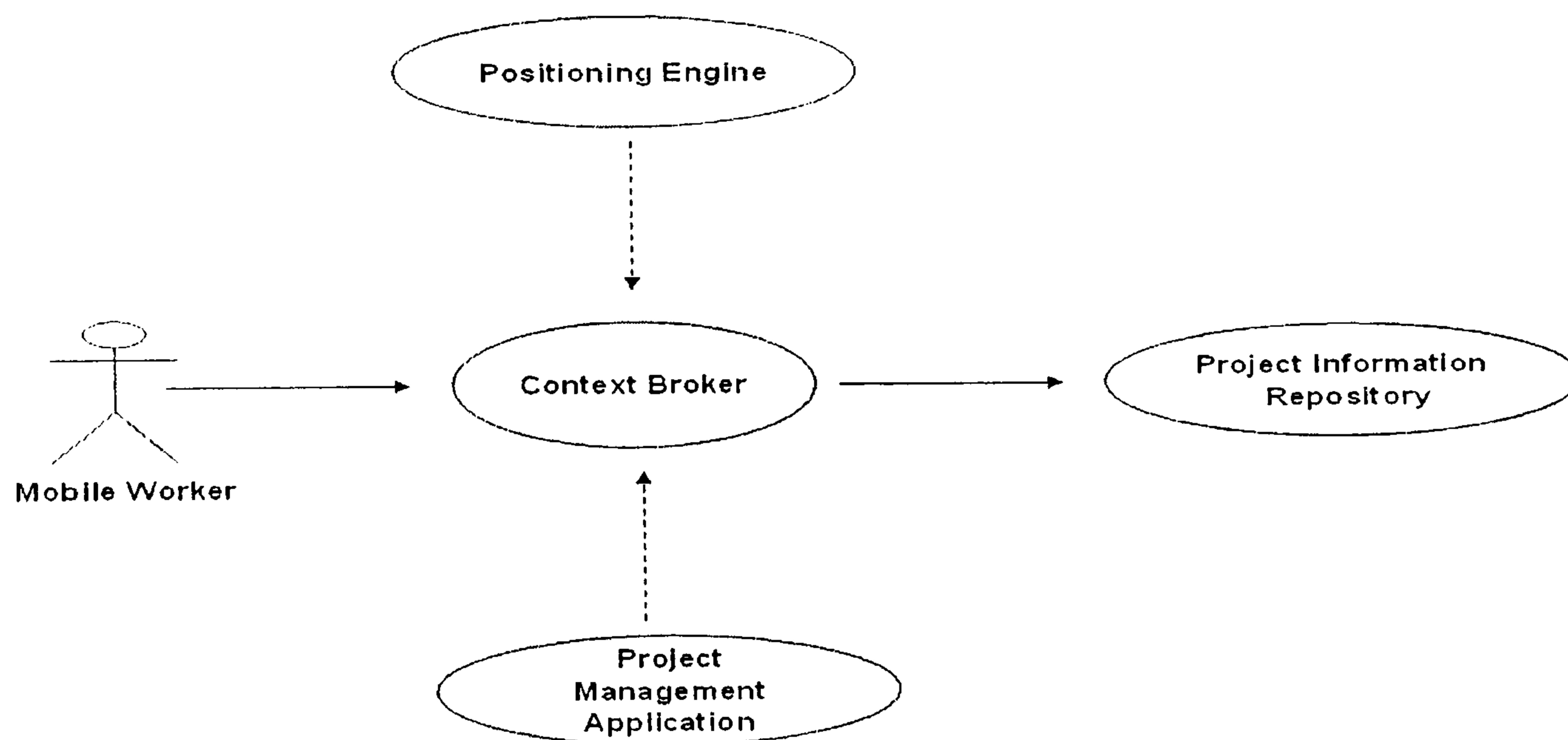


Figure 6-14: Context-aware Project Data Access Use-case

Pre-Conditions

- Same as in use-case Log-In (Section 6.8.2).

Flow of Events

Basic Path

1. The user clicks on the project data icon on the main screen.
2. The system retrieves the user context (e.g. location, time, profile, tasks, etc).
3. The system makes the list of relevant documents available to the user, based on his/her context.

4. The mobile worker selects a relevant document from the list.
5. The system makes the relevant documents available to the user.
6. The use-case ends

Alternative Paths

- The user overrides the context broker's suggestions and searches for another document manually.

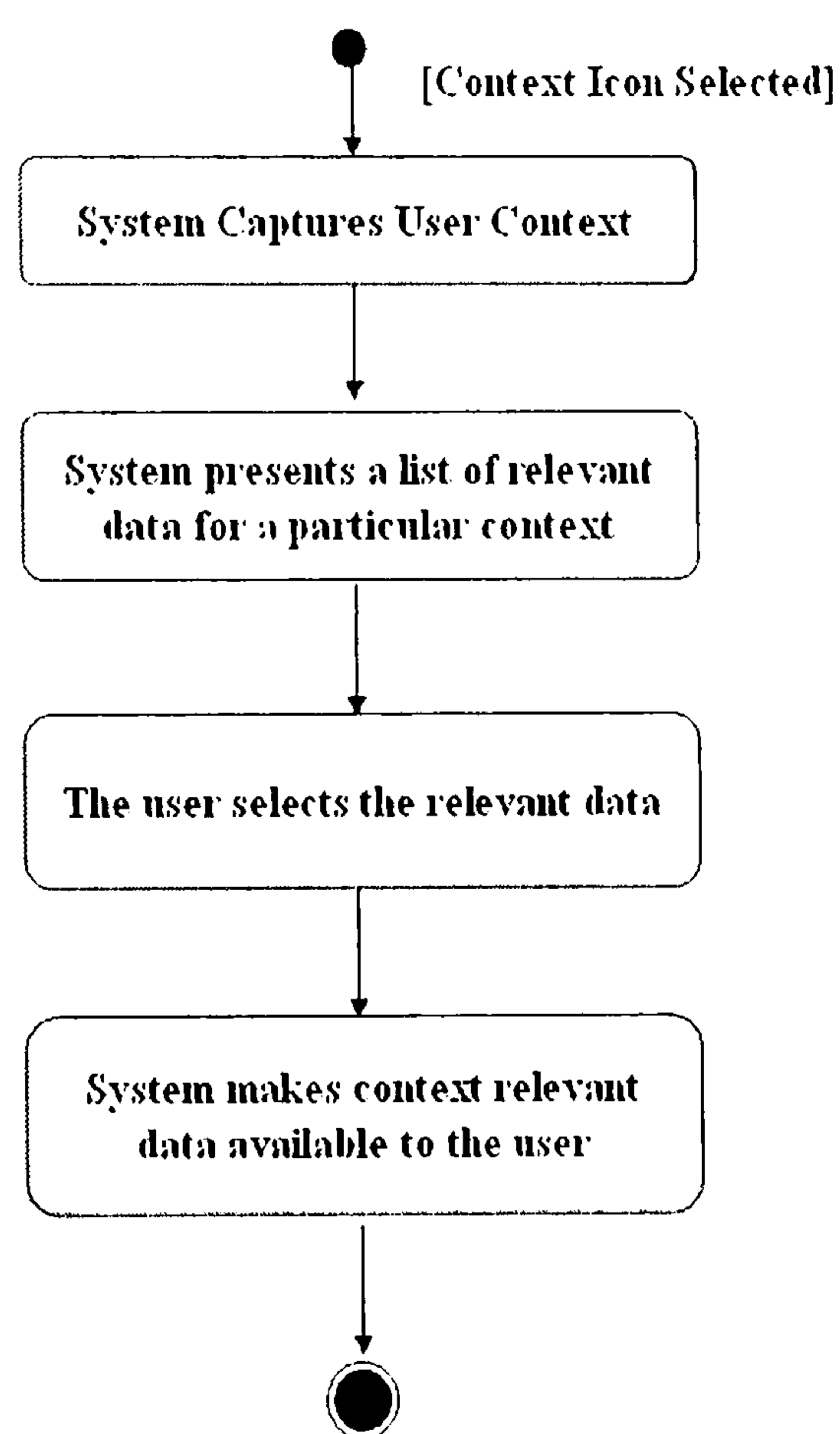


Figure 6-15: Context-Aware Project Data Access Activity Diagram

6.8.6. Use-Case: Tracking

This use-case describes the process by which the real time location of a mobile worker or a tagged equipment can be determined (Fig 6-16).

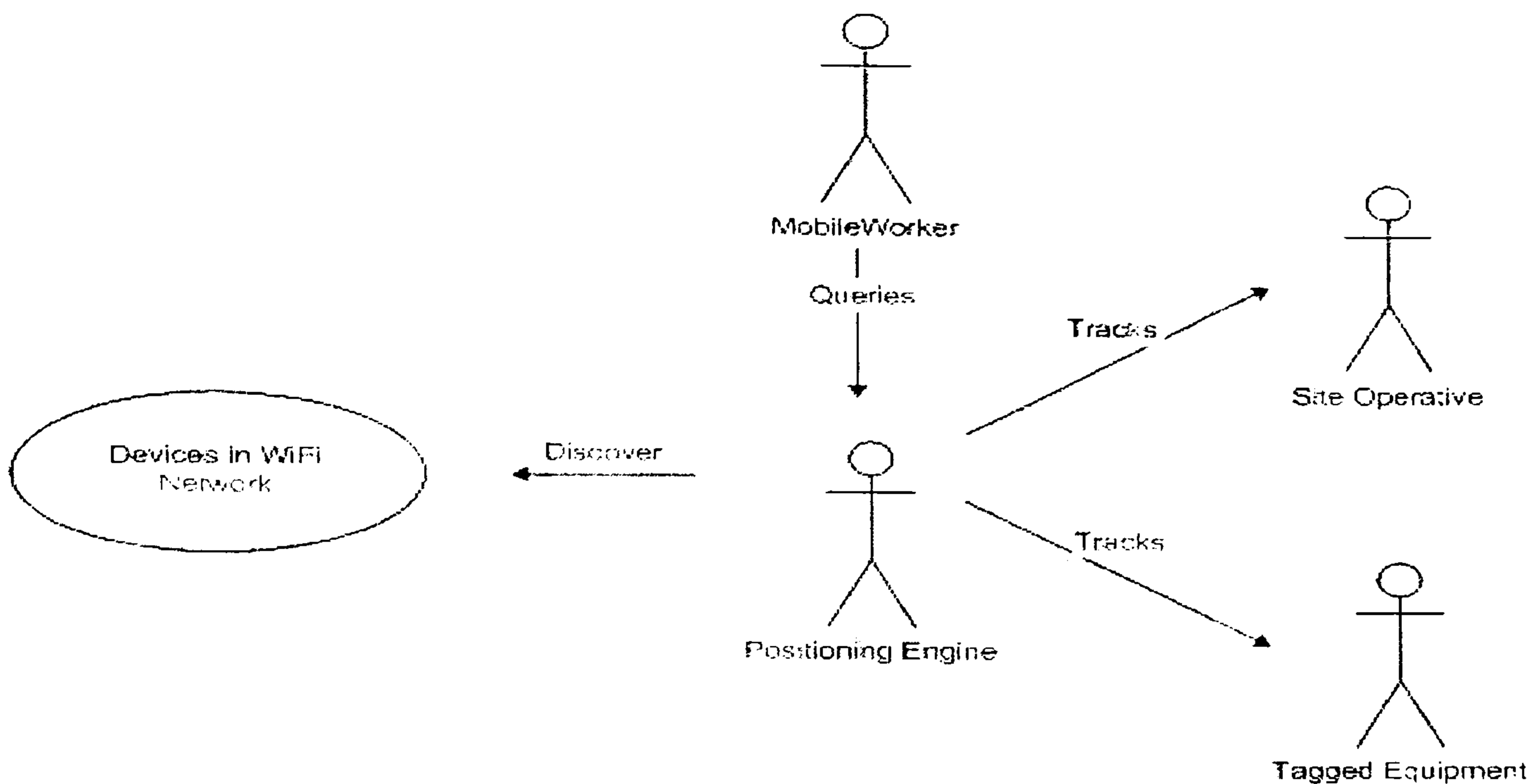


Figure 6-16: Use-case - Tracking site personnel/equipment

Pre-conditions

1. Same as in use-case- Log-In (Section 6.8.2).
2. Tracked equipment has an embedded tag, allowing its real time position determination.
3. Site personnel carry a device/tag, allowing their real time position to be measured.

Flow of Events

Basic Path

1. The user clicks on the tracking icon on the main screen.
2. The user selects an item to be tracked (e.g. a missing tool).
3. The user selects the track option.
4. The system provides dynamic location of the tracked item on the map.
5. The Positioning Engine updates the position of the tracked items at regular intervals.
6. The use-case ends.

Alternative Paths

1. The site supervisor can track all the staff working on-site, and their location.
2. The system generates a proactive warning message, if it finds a hazardous situation.

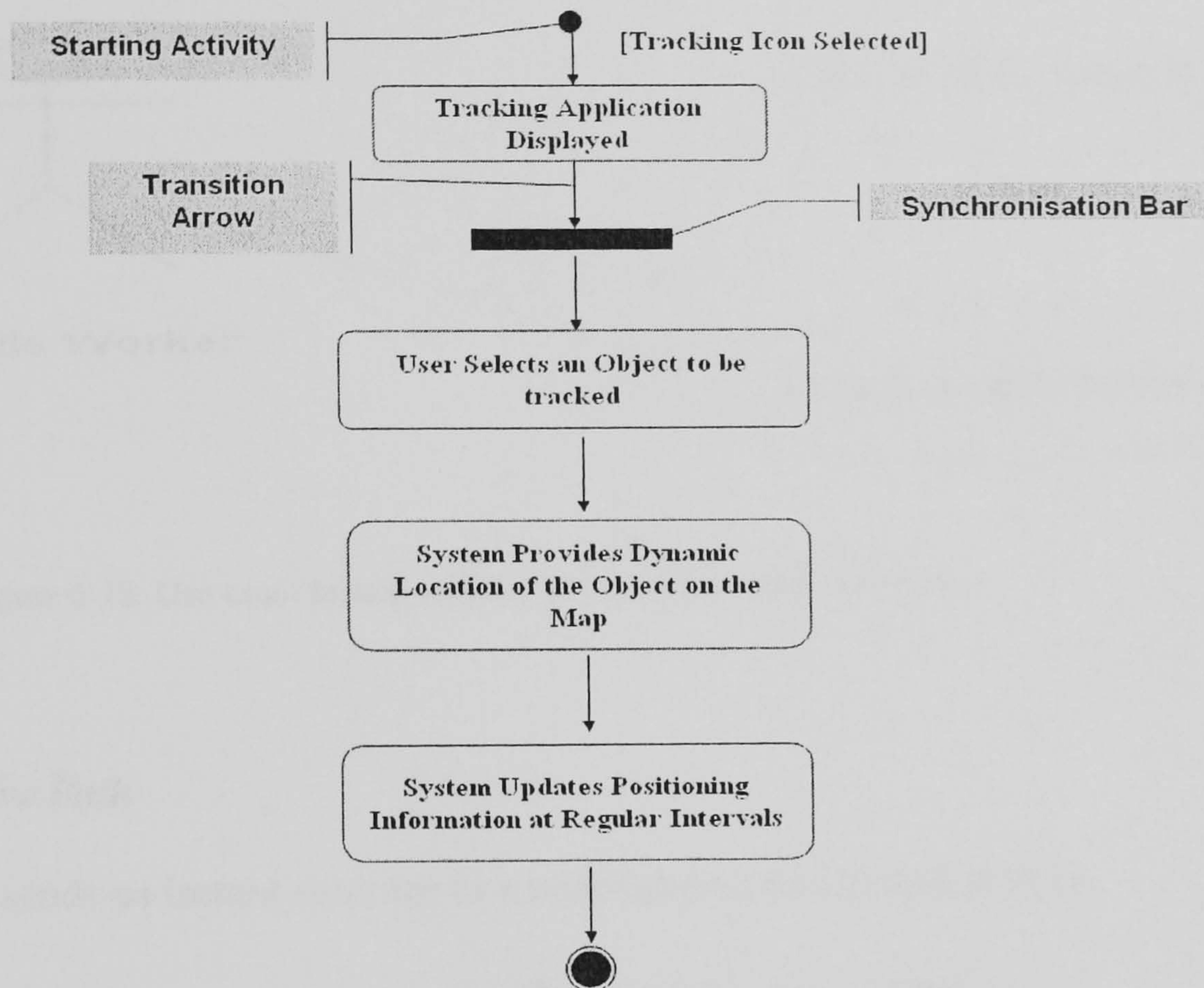


Figure 6-17: Activity Diagram- Tracking

6.8.7. Use-Case: Voice Over IP and Instant Messaging

This use-case describes the process by which a mobile worker can engage in voice conversation with his/her colleagues (both on-site or office based) or can send them instant messages (Figure 6-18).

Pre-conditions*Basic Path*

1. The mobile worker clicks on the Voice icon on the main screen.
2. The system launches the application.

3. The mobile worker checks the list of colleagues, who are available for voice conversation.
4. The user engages in voice conversation with the colleagues or send them an instant message.
5. The use-case ends.

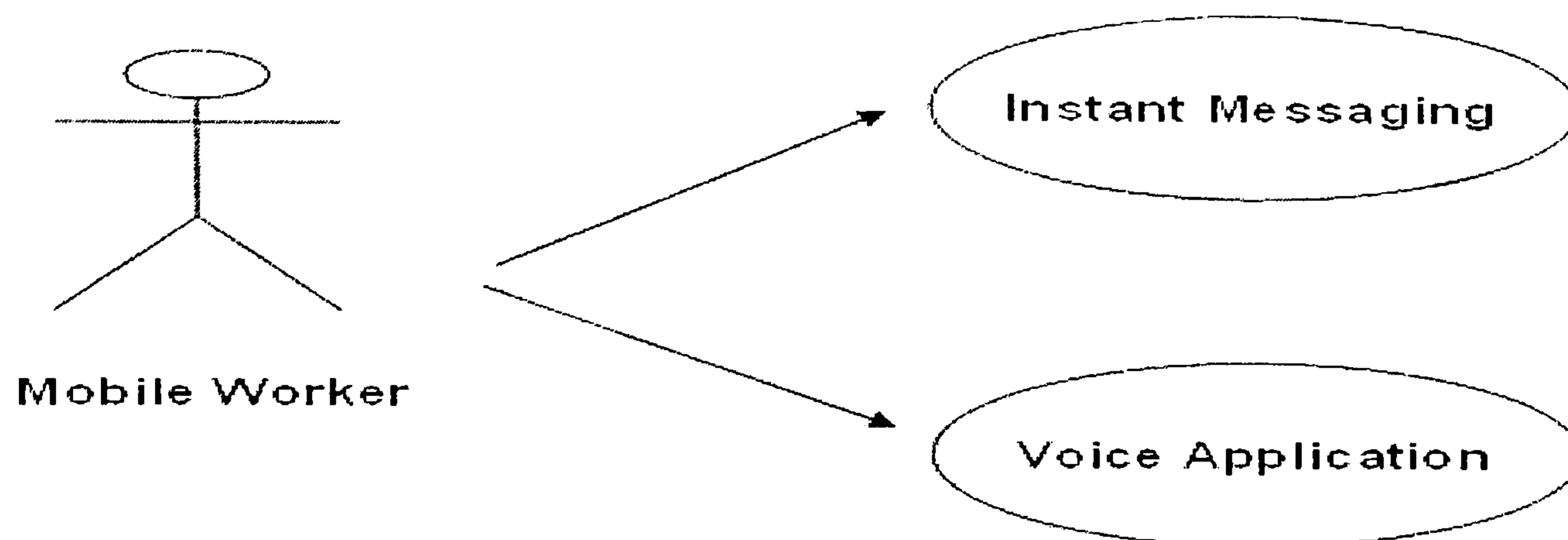


Figure 6-18: Use-case- Instant messaging and voice communication

Alternative Path

The user sends an instant message to a colleague on an as-needed basis.

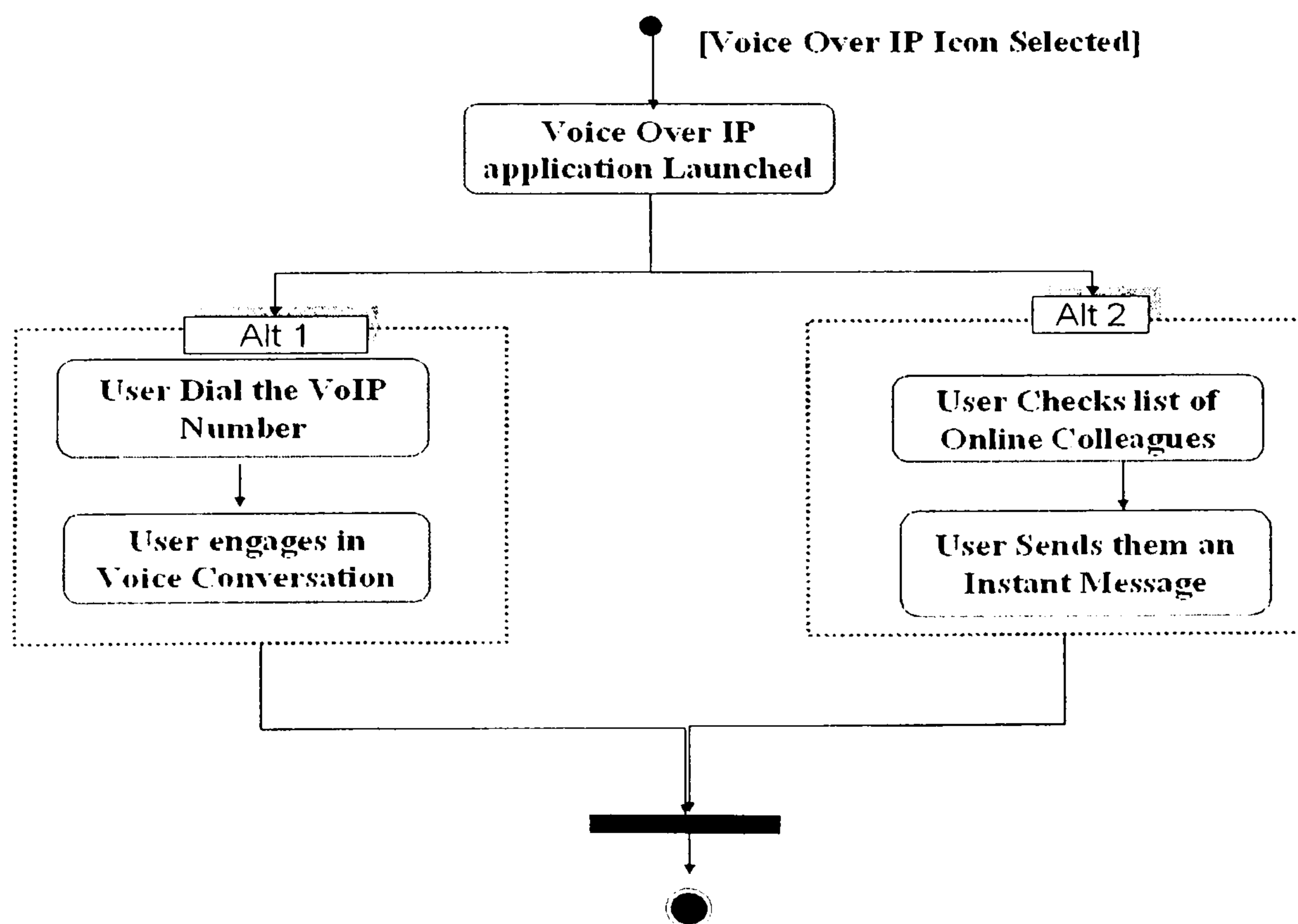


Figure 6-19: VoIP Activity Diagram

6.9. Summary

This chapter presented the design and architecture of the prototype system. Using a scenario-based needs analysis method (SUNA), user needs were first analysed and translated into system design goals. Based on these design goals, the system architecture was presented. Conceptual modelling of the system was done using UML with a use-case driven approach. Based on this, the next chapter presents the prototype implementation, which achieves the design goals articulated in this chapter.

Chapter 7: System Implementation and Operation

7.1. Introduction

Based on the system design (Chapter 6), this chapter presents the implementation of a prototype system that achieves the design goals articulated in Section 6.3. The implementation involves a proof of concept demonstration and an initial working model of a large, more complex system. A key objective of the system implementation was to demonstrate the feasibility of the concepts discussed in this research in realistic construction scenarios.

An important system design goal was scalability and flexibility (described previously in Section 6.3). Thus a component-based system development approach (Apperly et al, 2003) was adopted, and the system was implemented as a series of components (sub-systems). A component-based approach was also important to control the system complexity (as explained previously in Section 6.7). The prototype implementation was not entirely a bespoke development, and off-the-shelf components were used where they satisfied the system design criteria. This included the use of:

- MS Outlook application (Outlook, 2003) to provide task allocation support (explained in more detail in Section 7.3);
- Pocket-PC version of Microsoft Project (CyProj, 2005) to provide wireless project management support (explained in more detail in Section 7.3);
- Ekahau Positioning Engine (Ekahau, 2005), to provide WLAN based real-time location tracking support (explained in more detail in Section 7.6);

- Appear Provisioning Server (APS) (AppearNetworks, 2005) for service-provisioning support over the WLAN network. APS is explained in more detail in the following paragraph.

APS is a middleware technology that allows data and software applications to be distributed over the WLAN network, based on contextual parameters such as user location, time and mobile device IP address. Different prototype sub-systems developed in this work were integrated with APS and were distributed over the wireless network to Pocket-PC clients. Figure 7-1 shows key components of the system which are explained below.

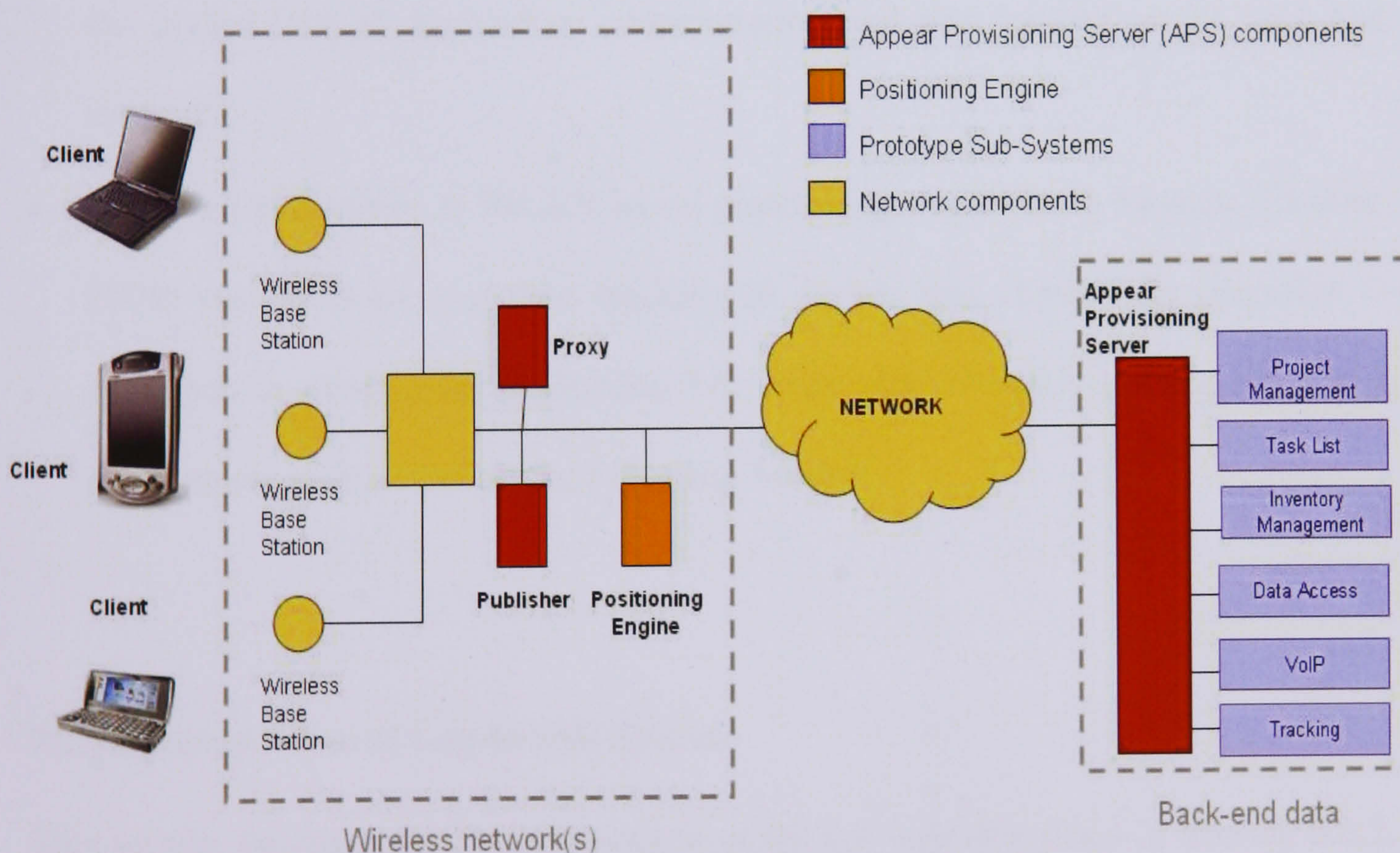


Figure 7-1: Service Delivery Architecture (Adapted from AppearNetworks, 2005)

- **Client Devices:** System served various WLAN enabled devices including Pocket PCs and Notebook based devices. These devices were also used to capture user context (i.e. user identity through the IP address of the mobile device, user-

location through real time tracking of the mobile device). Client devices also served the objective of providing users with context-relevant information.

- **Wireless Network:** Wireless network was set up using Linksys WLAN access points and Class 1 Bluetooth.
- **Server Components:** Key server components included a proxy, a publisher, a positioning engine and a provisioning server. All these components were set up on a notebook computer in the back-end network. The publisher handled mobile device detection and content update. The proxy server kept a cache of active user sessions and the most accessed services. This eliminated unnecessary traffic over the wireless network. The publisher handled device detection and changed the content on a mobile device, with changing user context. The provisioning server is the central part of application administration and was located in the back-end network.
- **Positioning Engine:** A WLAN based positioning engine from Ekahau (Ekahau, 2005) was used for real-time tracking of people and objects. Its operation is explained in more detail in Section 7.6, while implementation of the individual sub-systems is described in the following Section.

7.2. Implementation of Log-In Sub-System

This section describes the implementation of the use-case described in Section 6.8.2. The said use-case described the process by which an on-site wireless network detects the unique IP address of the WLAN-enabled mobile device and pushes a message prompting for a Log-In. On a successful log-in, the mobile worker can see a list of services relevant to his/her profile. To implement the sub-system, a stand-alone

Pocket-PC application was developed using the VisualStudio.net environment. On discovering a registered IP address, the server prompts the user to log-in (Fig 7-2-a). On a successful log-in (Fig 7-2-b), the system pushes a set of services to user's mobile device, based on the user-context (e.g. location, task, profile) (Fig 7-2-c). The user is then able to select the desired service simply by clicking on the relevant icon.

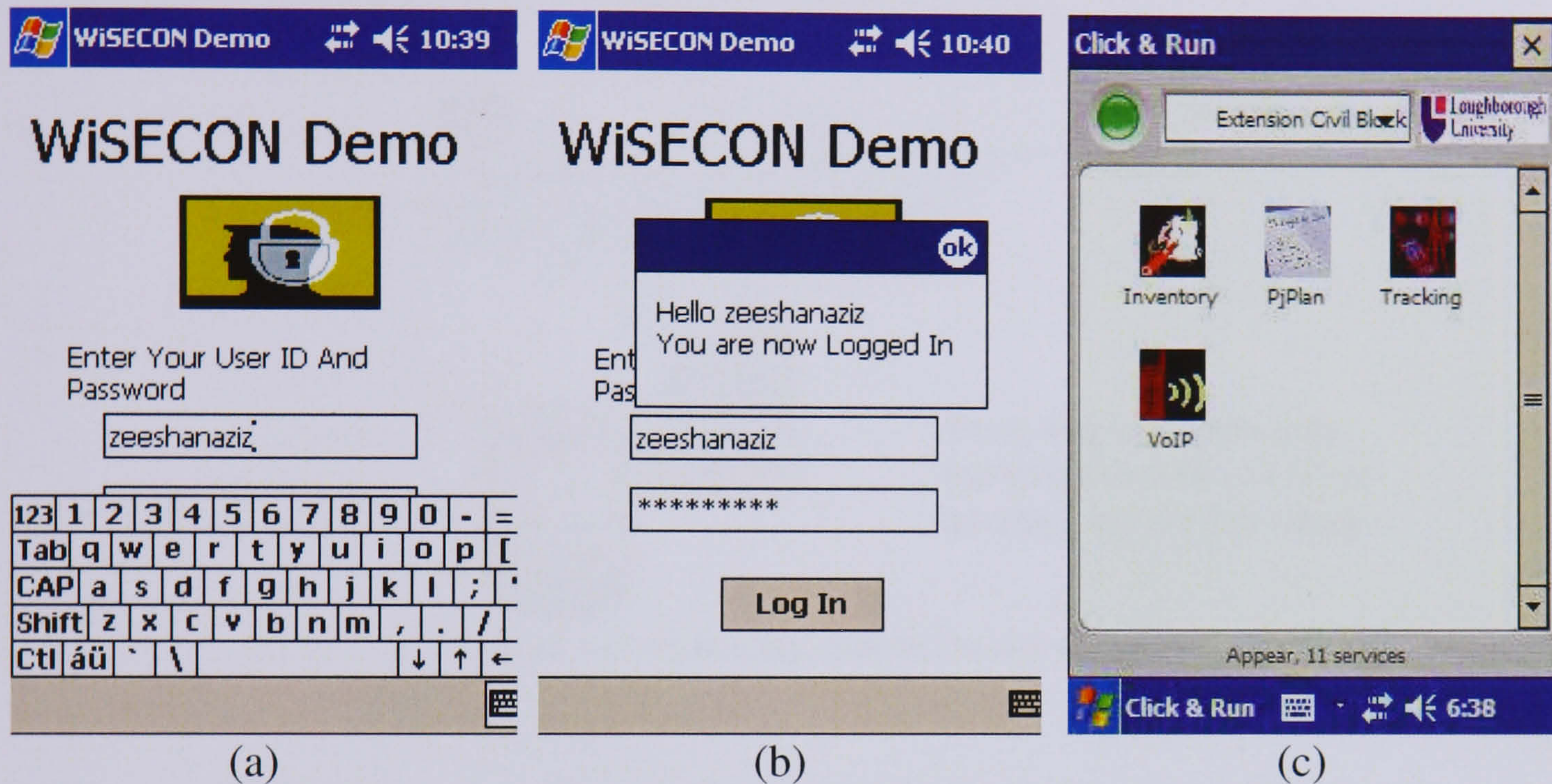


Figure 7-2: a) Data entry, b) confirmation of log-in and c) service provisioning

7.3. Implementation of Task Allocation & Project Management Sub-System

This section describes implementation of the use-case described in Section 6.8.3, which described the process by which tasks were allocated to mobile workers based on their profile. Subsequently, upon completion these tasks are updated in a project management application. To implement the functionality, Microsoft Outlook and Microsoft Project (along with their respective Pocket-PC versions) and Bluetooth wireless technology were used. It is assumed that prior to start of the shift, the site supervisor prepares a list of tasks¹ and associated method statements for mobile workers, and uploads this data on the site server (Fig 7-3). In the implementation, the server application was hosted on a notebook computer.

¹ It is also possible to retrieve the task data by integration with a project management application

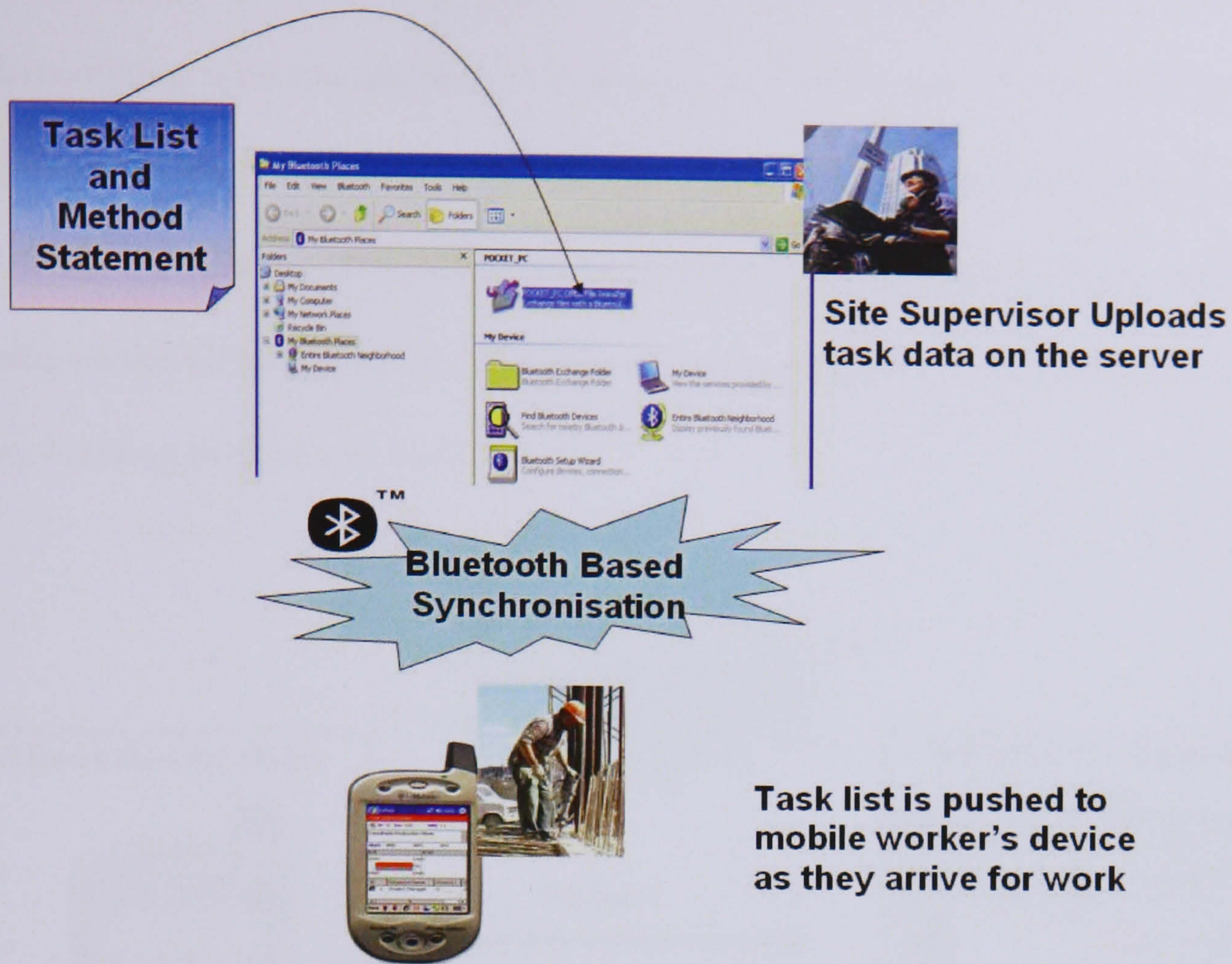


Figure 7-3: Uploading data on the site server

A Bluetooth wireless network was set up, which detects the unique IP address of the mobile devices, and the task-list was synchronised on discovery of a registered IP address (Fig 7-4-a). Clicking on the task details on the main interface (Fig 7-4-a) displays the task list (Fig 7-4-b). Clicking on a particular task displays the relevant task details (Fig 7-4-c).

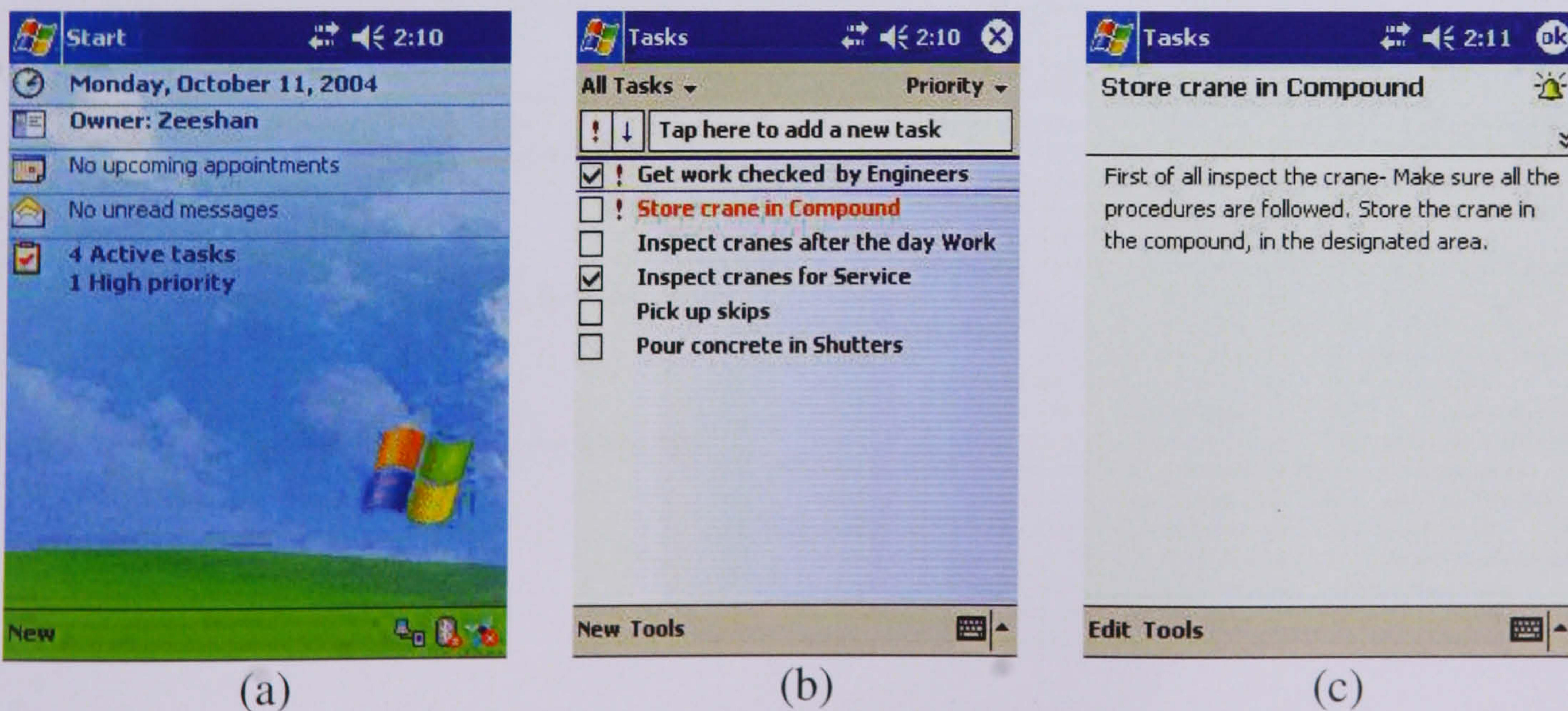


Figure 7-4: Task allocation to users

In order to help mobile workers update the project management plans, the prototype implementation used two off-the-shelf products i.e. Microsoft Project and Pocket-PC version of Microsoft Project (CyProj, 2004). The Bluetooth Wireless technology was used to synchronise the data between Pocket-PC and project management application running on the server (Fig 7-5). For demonstration purposes, a project plan of a three storey building project was used (Fig 7-6).

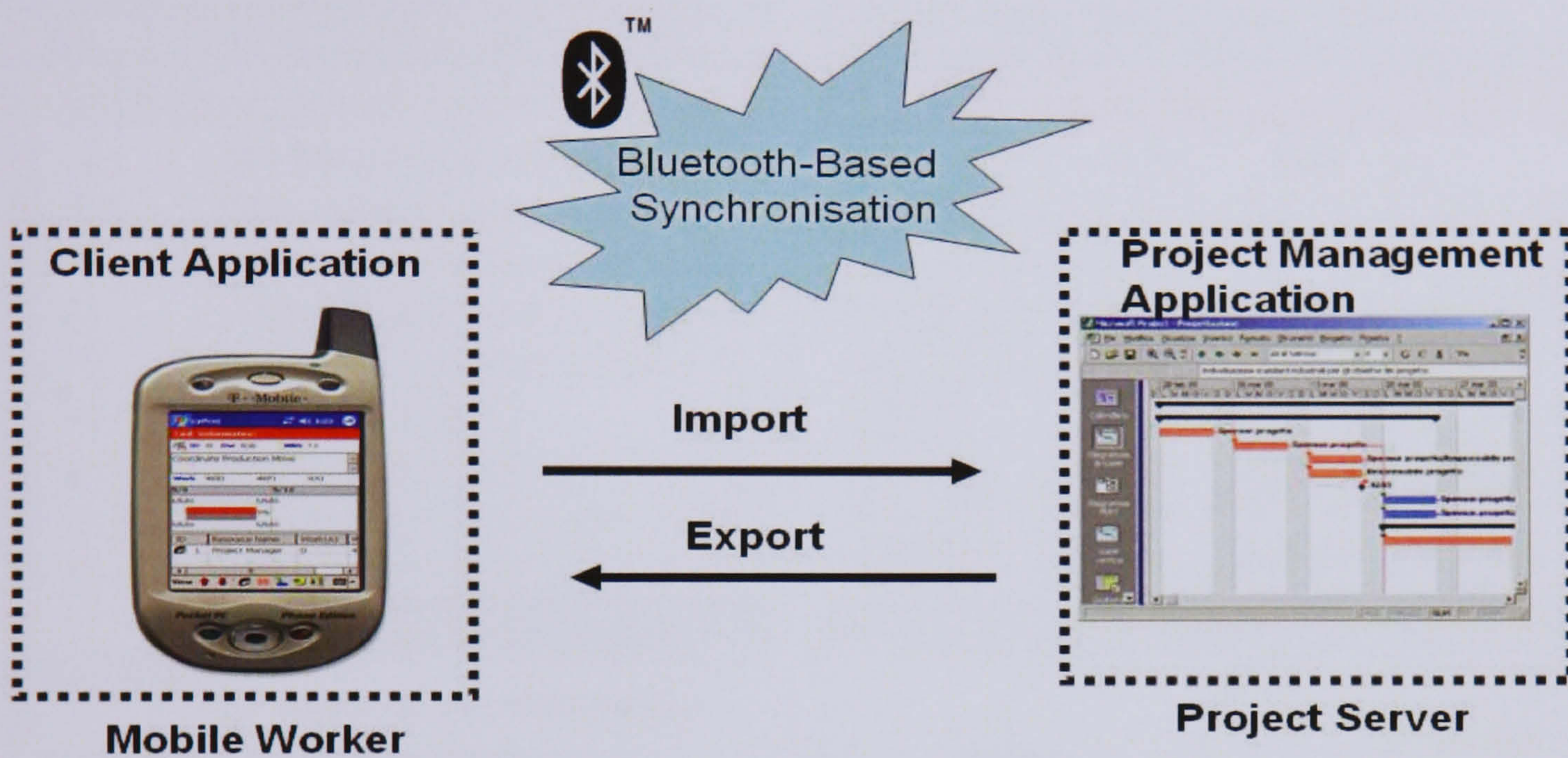


Figure 7-5: Real time updates of project data using Bluetooth

Install pneumatic tube in elevator pit	3 days	Mon 05/04/04	Wed 07/04/04	43	Elevator contractor
Prepare and pour concrete floor in elevator pit	1 day	Thu 08/04/04	Thu 08/04/04	45	G.C. concrete crew
Steel Erection	45 days	Fri 23/04/04	Thu 24/06/04		
Erect steel columns, beams, and joist - 1st and 2nd floors	2 wks	Fri 23/04/04	Thu 06/05/04	44,17	Steel erection contractor
Erect steel columns, beams, and joist - 3rd floor and roof	2 wks	Fri 07/05/04	Thu 20/05/04	48	Steel erection contractor
Install miscellaneous iron and bracing - 1st and 2nd floors	2 wks	Fri 07/05/04	Thu 20/05/04	48	Steel erection contractor[75%]
Install miscellaneous iron and bracing - 3rd floor and roof	2 wks	Fri 21/05/04	Thu 03/06/04	49	Steel erection contractor[75%]
Install stairs and miscellaneous iron railing	2 wks	Fri 04/06/04	Thu 17/06/04	51	Steel erection contractor[50%]
Touch-up paint on steel	1 wk	Fri 18/06/04	Thu 24/06/04	52	Steel erection contractor[20%]
Form and Pour Concrete - Floors and Roof	85 days	Fri 07/05/04	Thu 02/09/04		
Form 2nd floor including all floor openings	5 days	Fri 25/06/04	Thu 01/07/04	53,14	G.C. rough carpenter crew,G.C.
Install rebar and in-floor utilities (including mechanical, electric	5 days	Fri 07/05/04	Thu 13/05/04	48	G.C. labor crew[33%],Plumbing
Pour 2nd floor slab	4 days	Fri 02/07/04	Wed 07/07/04	56,55	G.C. concrete crew
Cure 2nd floor slab	7 days	Thu 08/07/04	Fri 16/07/04	57	G.C. labor crew[10%]
Strip forms from 2nd floor slab	2 days	Mon 19/07/04	Tue 20/07/04	58	G.C. labor crew
Form 3rd floor including all floor openings	5 days	Mon 19/07/04	Fri 23/07/04	58	G.C. rough carpenter crew[50%
Install rebar and in-floor utilities (including mechanical, electric	5 days	Mon 19/07/04	Fri 23/07/04	58	G.C. labor crew[33%],Plumbing
Pour 3rd floor slab	4 days	Mon 26/07/04	Thu 29/07/04	61,60	G.C. concrete crew
Cure 3rd floor slab	7 days	Fri 30/07/04	Mon 09/08/04	62	G.C. labor crew[10%]
Strip forms from 3rd floor slab	2 days	Tue 10/08/04	Wed 11/08/04	63	G.C. labor crew
Form roof slab including all floor openings	5 days	Tue 10/08/04	Mon 16/08/04	63	G.C. rough carpenter crew,G.C.
Install rebar and in-floor utilities (including mechanical, electric	5 days	Tue 10/08/04	Mon 16/08/04	63	G.C. labor crew[33%],Plumbing
Pour roof slab	4 days	Tue 17/08/04	Fri 20/08/04	66,65	G.C. concrete crew
Cure roof slab	7 days	Mon 23/08/04	Tue 31/08/04	67	G.C. labor crew[10%]
Strip forms from roof slab	2 days	Wed 01/09/04	Thu 02/09/04	68	G.C. labor crew
Form 1st floor	4 days	Wed 21/07/04	Mon 26/07/04	59	G.C. rough carpenter crew
Install electrical underground	1 wk	Wed 21/07/04	Tue 27/07/04	59	Electric contractor
Install plumbing underground	1 wk	Wed 21/07/04	Tue 27/07/04	59	Plumbing contractor
Install rebar and in-floor utilities	4 days	Wed 21/07/04	Mon 26/07/04	59	G.C. labor crew[33%],Plumbing

Figure 7-6: Project Plan of a Three Storey Construction Project

In the implementation scenario, it was assumed that the steel erection contractor has informed the site supervisor that there will be a two-day delay in the erection of steel columns, beams and joist for the 1st and 2nd floors. The site supervisor updates the project management plans using his mobile device (Fig 7-7). Using the Bluetooth Wireless technology, this information is updated in real-time on the project management application running on the server.

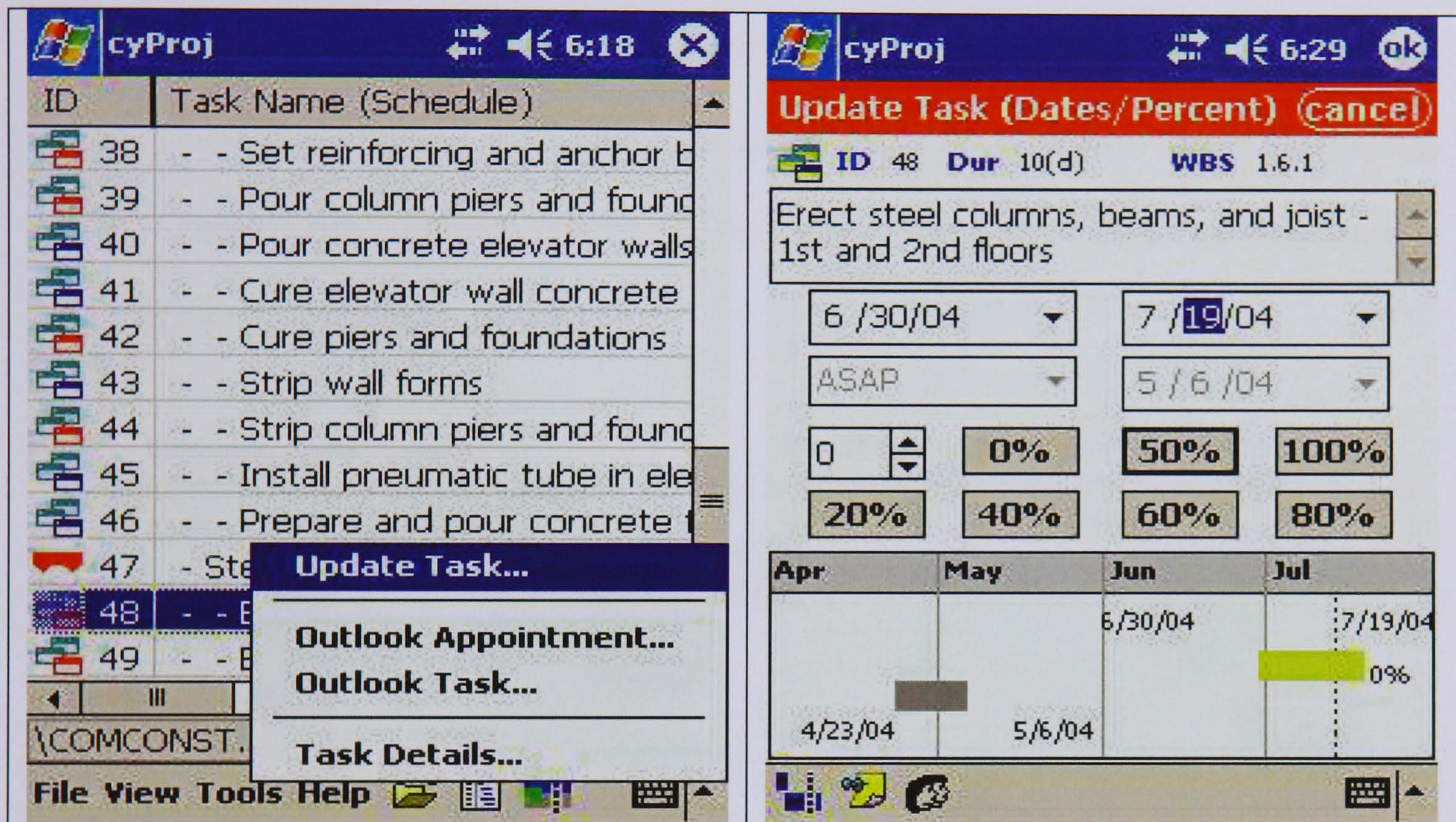


Figure 7-7: User selects a) the task to be updated and b) choose task update option

The implementation of this sub-system demonstrates the potential of allocating tasks and task-details to mobile workers based on their profile. Such a task allocation mechanism can provide mobile workers with detailed information about the task at hand. At the same hand, it can be used to enhance accountability, by keeping a track of all tasks allocated and completed. At the same time, the potential of updating project management plans from the point-of-work is demonstrated. Such applications of technology can help project managers in real-time progress monitoring of on-site works.

7.4. Implementation of Inventory-Logistics Sub-System

Figure 7-8 illustrates the implementation of the use-case described in Section 6.8.4. In the implementation scenario, tags are used to automate the information flow across the supply chain and contain important information about the bulk delivery. As soon as the delivery arrives at the construction site, an on-site wireless network scans the tag attached to the bulk delivery and sends an instant message to site supervisors' mobile device, prompting him/her to confirm the delivery receipt. Once the delivery receipt is confirmed, data is stored locally on the site supervisor's mobile device, which is subsequently synchronised with the site-server (using Bluetooth), resulting in an update of the inventory database.

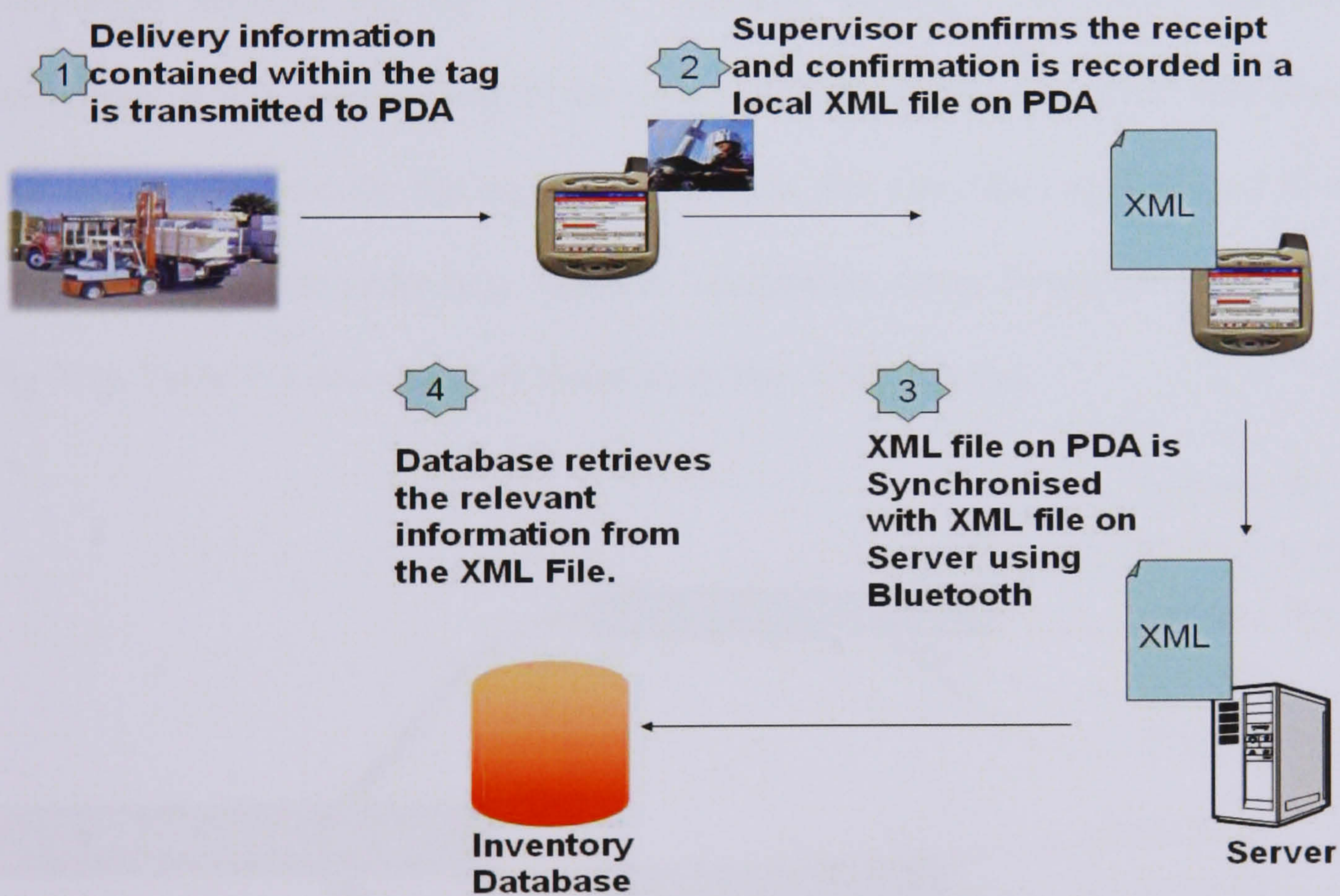


Figure 7-8: Implementation of Inventory Logistics Use-Case

There were two key challenges in the proposed implementation, including:

- **Describing the Information Structure:** It was important to describe structure of information stored within the tag, so that it can be queried across the supply chain; and
- **Application Development:** The second key challenge was to develop an application, capable of displaying the tag data, thereby allowing the site supervisor to browse through the individual contents of the delivery and to confirm the receipt (or record any discrepancies).

7.4.1. Describing the Information Structure:

In the prototype implementation, XML was used as a mechanism to store and exchange information between the tag and the back-end system. To ensure information consistency, it was assumed that all the supply chain partners have agreed on a standard XML-schema to describe the tag information. In this case, the tag was used to store information about the order (e.g. Supplier Information, Order Details, Product Details) (Fig 7-9). Table 7-1 describes key elements of the XML schema.

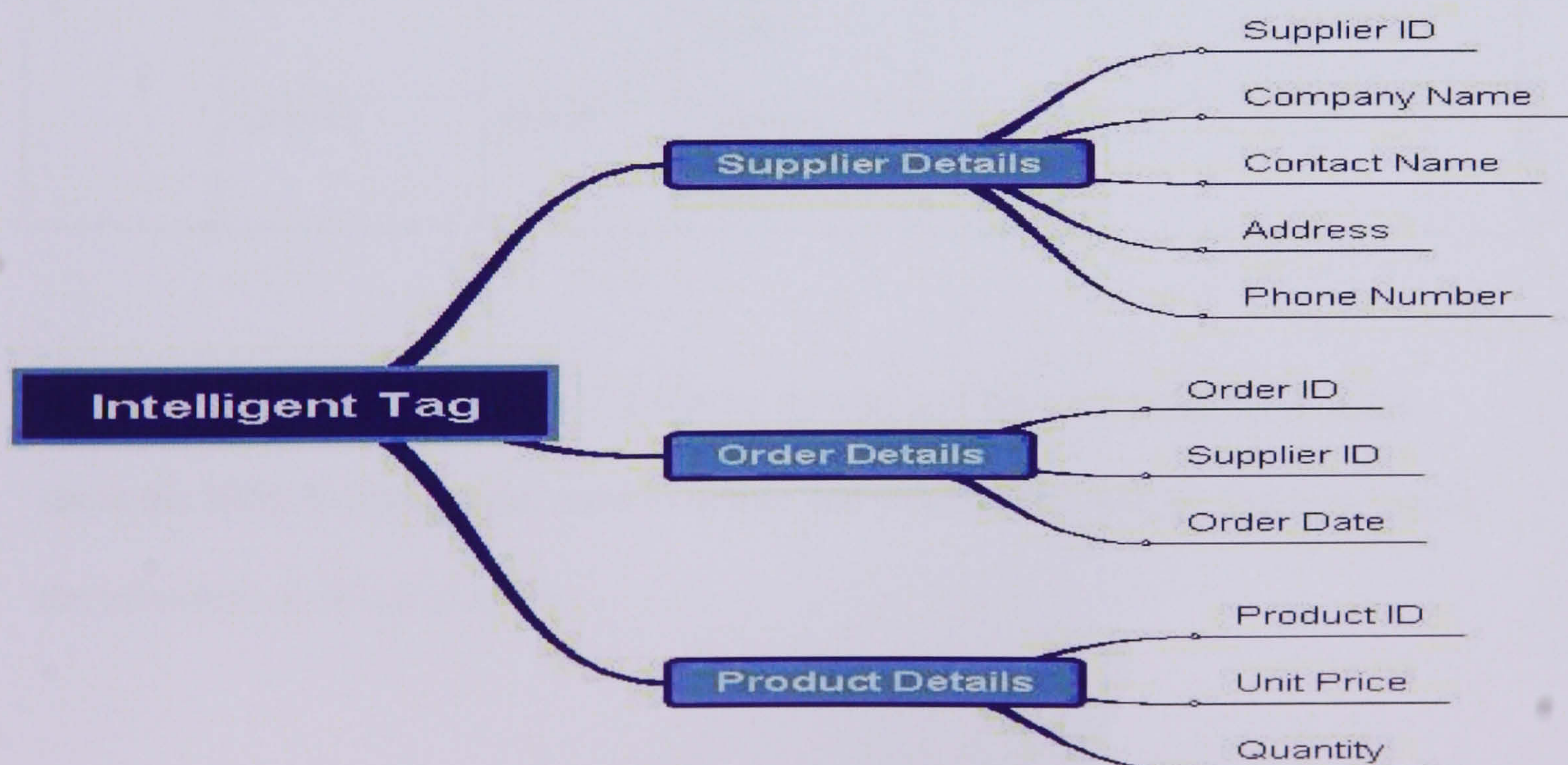


Figure 7-9: Information Contained within an Intelligent Tag

Table 7-1 : Description of the Inventory Schema

Inventory Schema				
Element	Attribute	Type	Cardinality	Description
Supplier	SupplierID	String	One	Unique ID of the Supplier
	CompanyName	String	Required Single	Suppliers' name
	ContactName	String	Required Single	Suppliers' contact person
	Address	String	Required Single	Suppliers' Address
	Phone	String	Required Single	Suppliers' Phone Number
Orders	OrderID	String	One	Unique ID number of the Order
	SupplierID	String	Required Single	Unique ID number of the supplier
	OrderDate	String	Required Single	Order Date
Product Details	OrderID	String	One	Unique identifier for the order
	ProductID	String	Required Single	Unique identifier for the product
	Unit Price	String	Required Single	Unit Price
	Quantity	String	Required Single	Quantity

Box 7-1 (Supplier details), Box 7-2 (Order details) and Box 7-3 (Product details)

show the XML Schema code, used to define and validate the content and structure of the information stored in a tag.


```

<xs:element name="Supplier">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="SupplierID" type="xs:string" minOccurs="0" />
      <xs:element name="CompanyName" type="xs:string" minOccurs="0" />
      <xs:element name="ContactName" type="xs:string" minOccurs="0" />
      <xs:element name="Address" type="xs:string" minOccurs="0" />
      <xs:element name="Phone" type="xs:string" minOccurs="0" />
    </xs:sequence>
  </xs:complexType>
</xs:element>

```

Box 7-1: XML Schema for Describing Supplier Information

```

<xs:element name="Orders">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="OrderID" type="xs:int" minOccurs="0" />
      <xs:element name="SupplierID" type="xs:string" minOccurs="0" />
    </xs:sequence>
  </xs:complexType>
</xs:element>

```

Box 7-2: XML Schema for Describing Order Details

```

<xs:element name="Product Details">
  <xs:complexType>
    <xs:sequence>
      <xs:element name="OrderID" type="xs:int" minOccurs="0" />
      <xs:element name="ProductID" type="xs:string" minOccurs="0" />
    </xs:sequence>
  </xs:complexType>
</xs:element>

```

Box 7-3: XML Schema for Describing Product Details

7.4.2. Application Development

The prototype application consisted of three forms:

- The Data Source Form, to load the data from XML file;
- The Company Form, to display supplier's details from the XML file; and
- The Orders Form, to display order details from the XML file.

These forms are explained in more detail below.

7.4.2.1. Data Source Form

In the implementation scenario, as soon as a delivery tag arrives on the site, the site server scans the tag to read the tag data and pushes an instant message to the site supervisor to confirm the delivery receipt. To simulate a similar scanning and information push process, an XML file (Fig 7-10), containing the tag's data was stored locally on the site supervisor's Pocket-PC device.

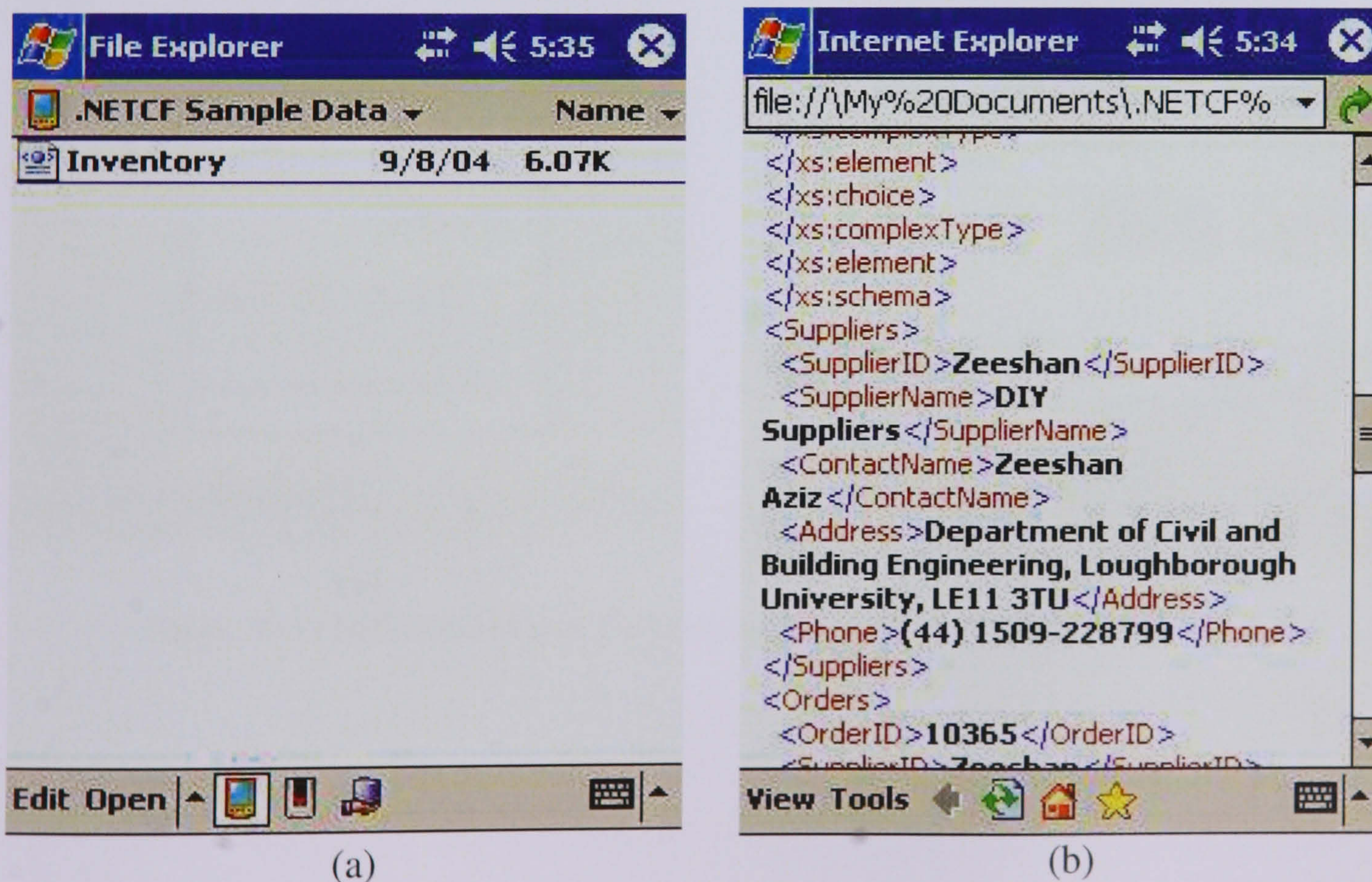
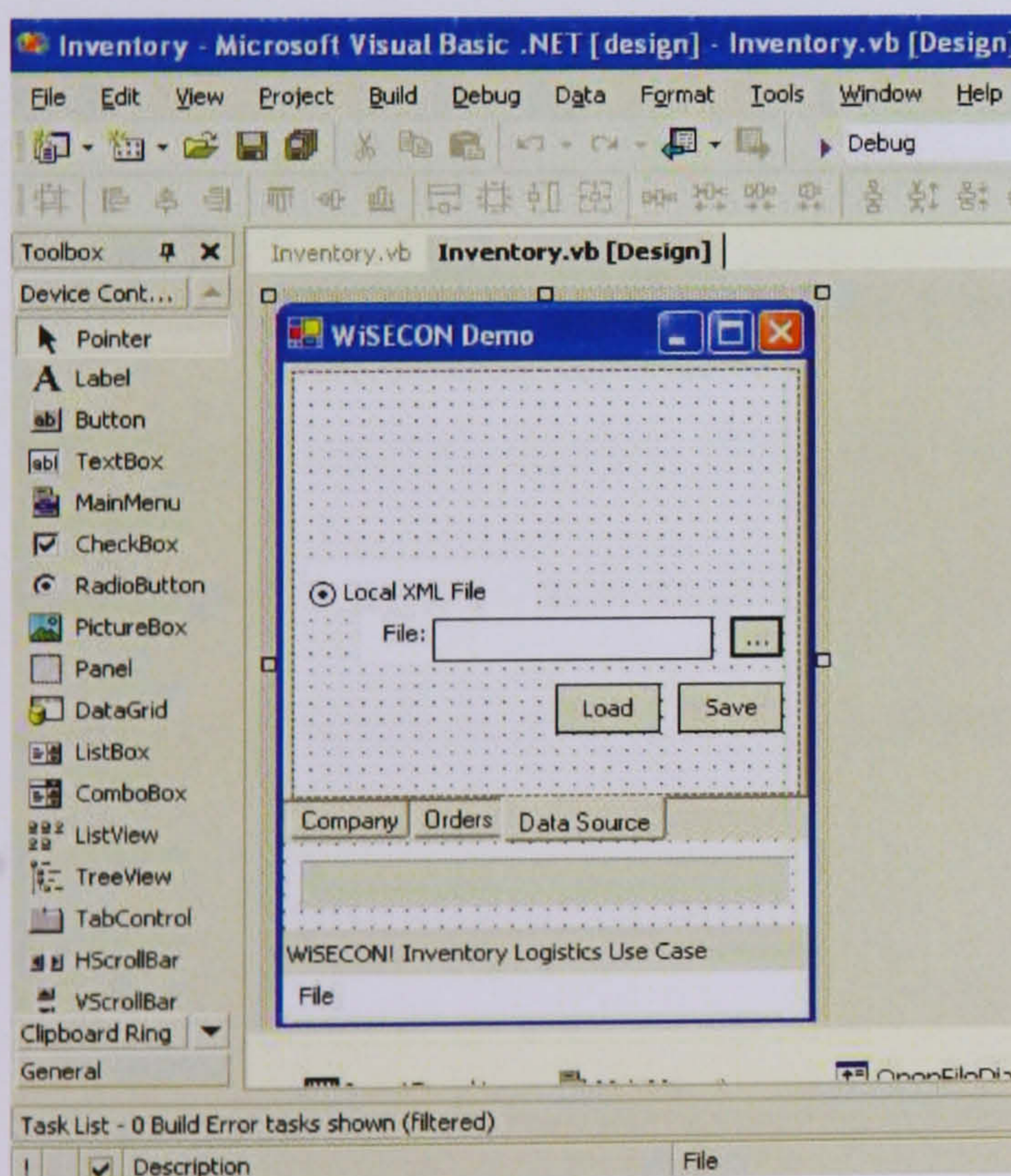


Figure 7-10: Inventory.XML file, which served as the data source.

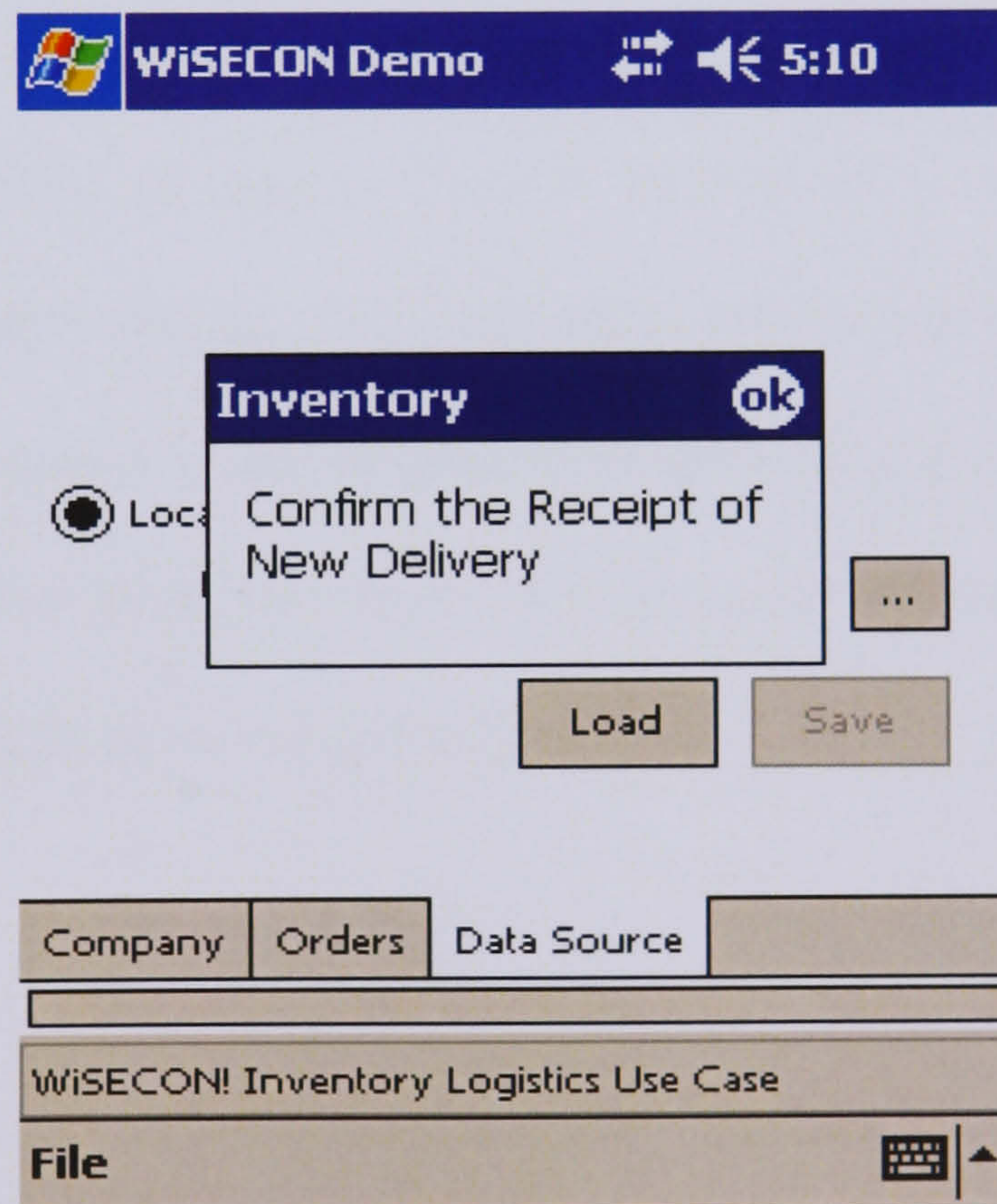
VisualStudio.net development environment (Fig 7-11-a) was used for application development, while Windows forms were used for user interface development. On receipt of a new delivery, site supervisor will receive an instant message “Confirm the Receipt of New Delivery” (Fig- 7-11 b) and data will be loaded on the window forms from the XML file (as described in Figure 7-12-b).

7.4.2.2. Company Form

The Company form contains the supplier, contact, phone, and address details (Fig 7-12-a). Selecting a particular supplier in the supplier combo-box loads relevant supplier’s data from the XML file. Fig 7-12 shows design and run-time views of the company forms.

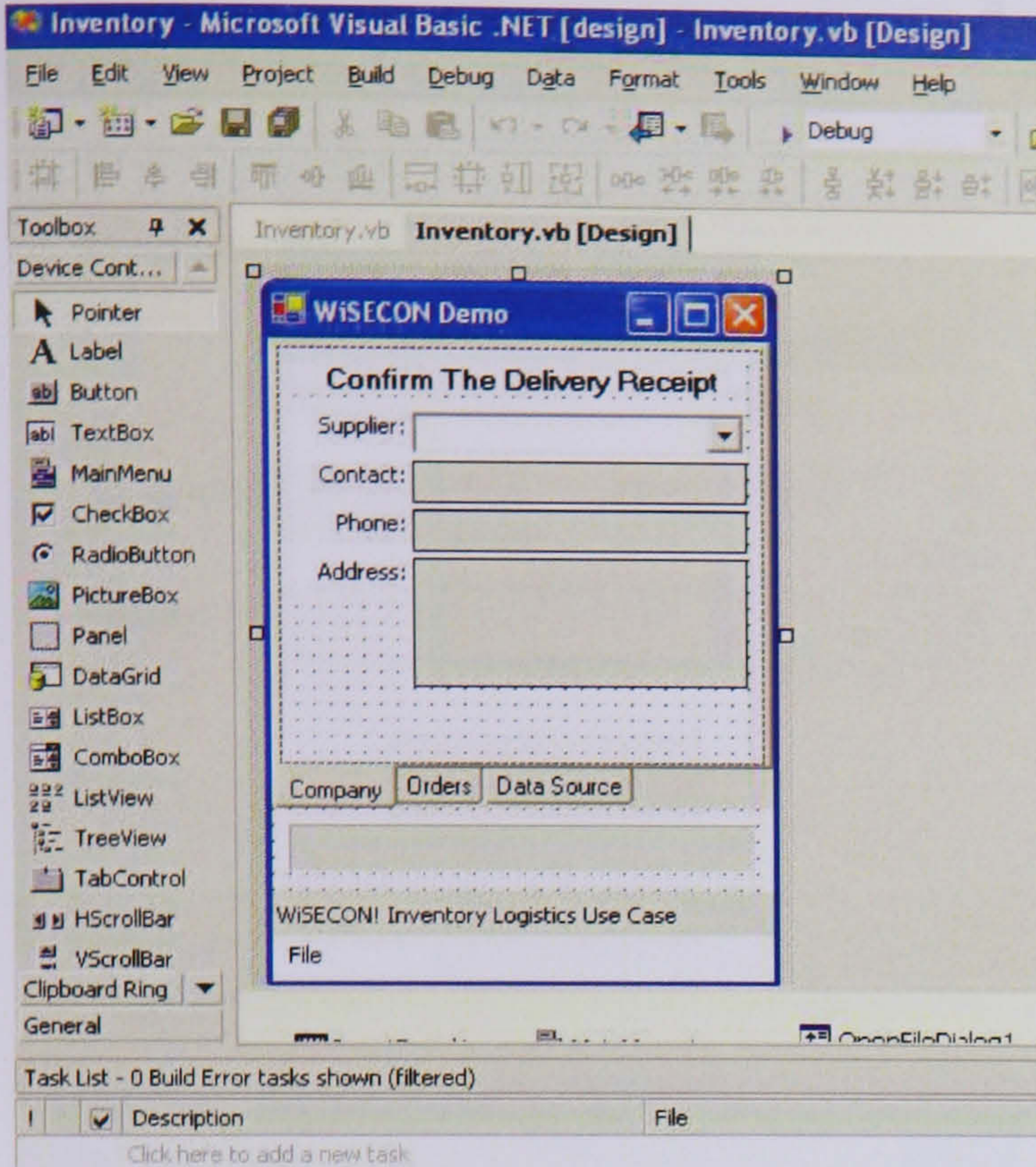


(a)

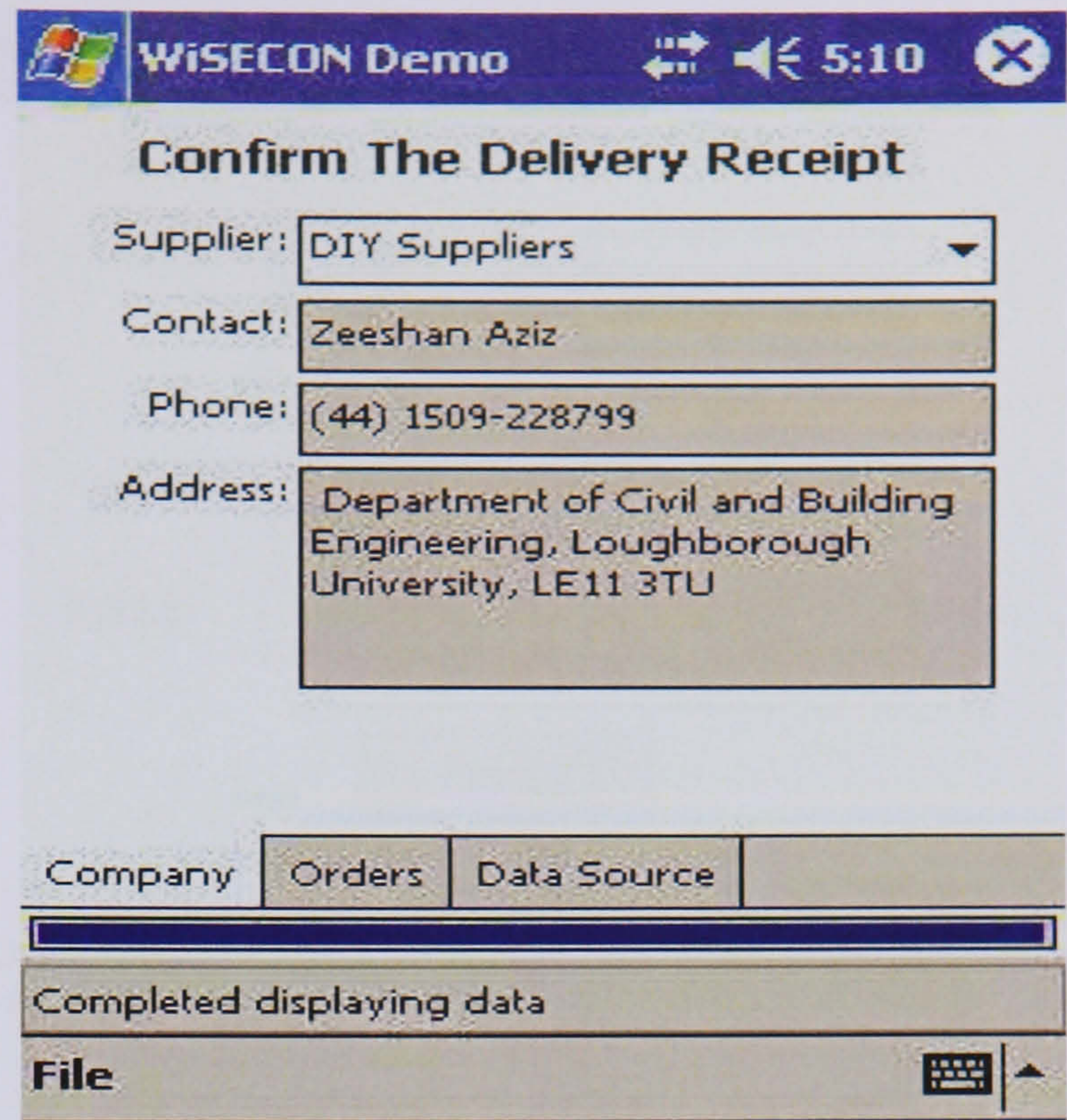


(b)

Figure 7-11 : Data Source Form- (a) Design Time and (b) Run Time View



(a)

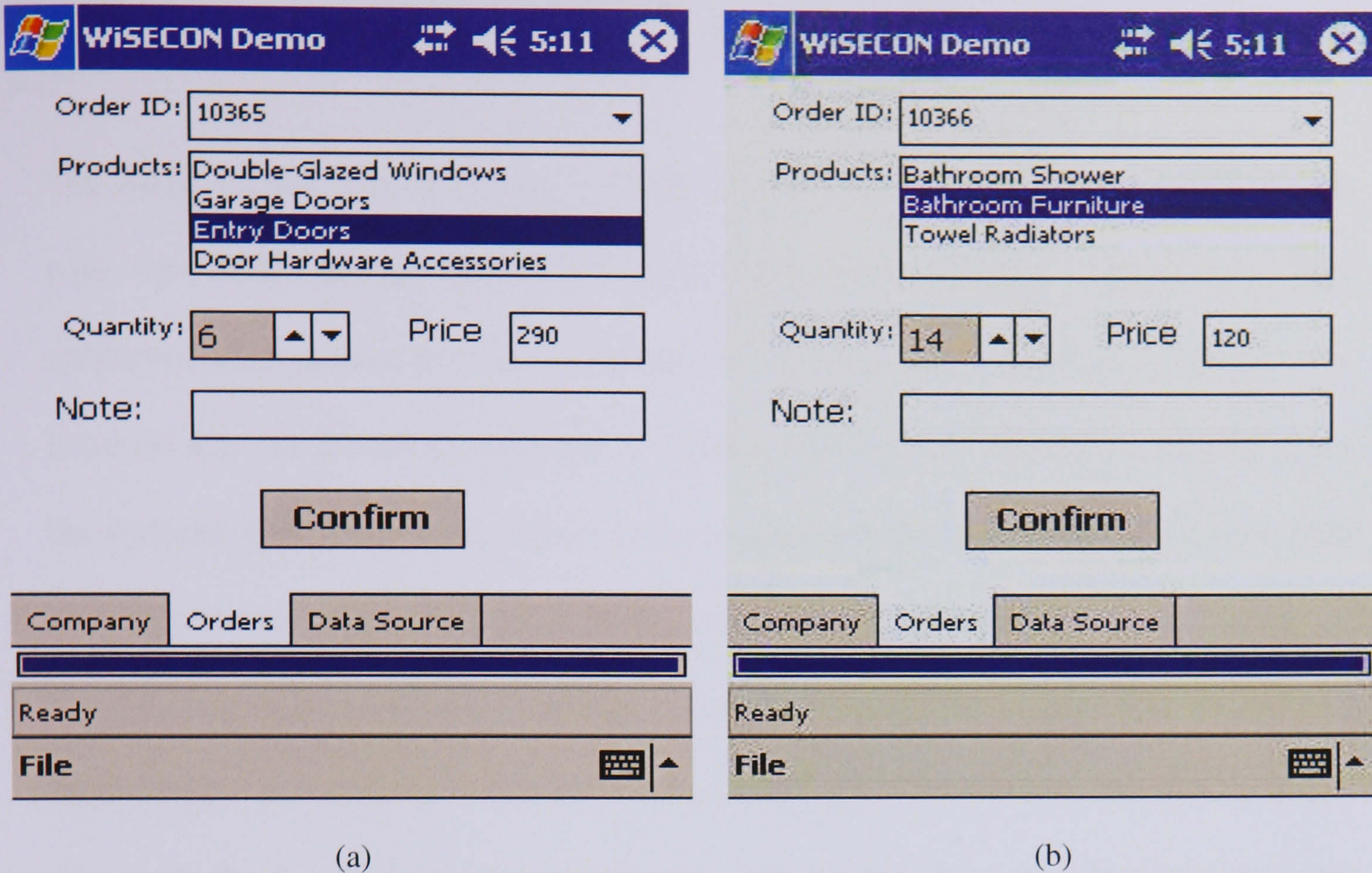


(b)

Figure 7-12: Company Form – Design Time (a) and Run-time view (b)

7.4.2.3. Order Form

The Order form contains the Order ID (i.e. unique ID of an order from a particular supplier), Products (i.e. list of products within an order), Quantity (i.e. quantity of each product), Price (i.e. price of each product), and note (i.e. a text box for recording any discrepancies) entries. Selecting a particular order in OrderID combo-box will display a list of products contained within that particular order. Selecting a particular order (i.e. 10365 or 10366 in Fig 7-14) displays the corresponding details.

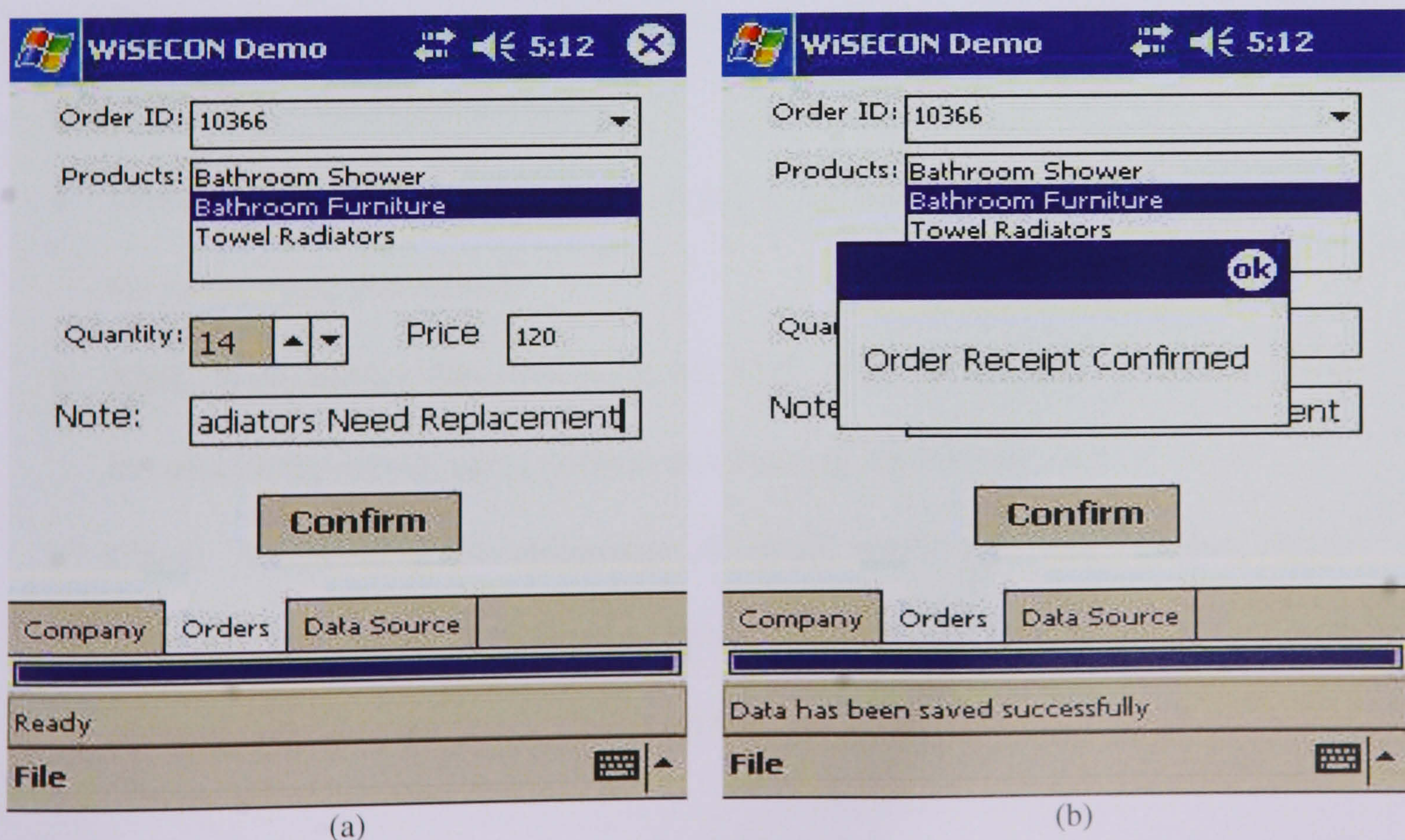


(a)

(b)

Figure 7-13: Orders Form- Run-Time View

Using the order form it is also possible to browse through the individual delivery contents and to record any discrepancies if there are any (Fig 7-14-a), On clicking the confirm button, a message “Order Receipt Confirmed” is displayed (Fig 7-14-b) and any alteration in the data is recorded in the local XML file.



(a)

(b)

Figure 7-14: (a) Recording discrepancies and (b) confirming the order receipt

The XML on the mobile worker's Pocket-PC device is subsequently synchronised with the XML on the server using the Bluetooth Wireless technology. This synchronisation is done in order to update the inventory database of any changes. It is assumed that the inventory database is XML-compliant and reads data directly from the updated XML file on the server. Information from updated XML file is then read back in real time into an inventory database, compliant with XML.

The implementation of this sub-system has demonstrated the critical role the tagging technologies can play in bringing intelligence to the construction-site environment. Although the focus in this implementation was on inventory-management, tags can possibly be used for a wide range of different applications.

7.5. Implementation of Context-aware Project Data Access Sub-System

This section describes the implementation of the use-case described in Section 6.8.5, which explained the process by which information is delivered to mobile workers based on their existing context. Implementation essentially consisted of three steps (Fig 7-15) which are explained below:

- **Server Application Development:** A server application was developed, where all the project data was stored;
- **XML Web Service Development:** An XML Web Service was written, to query the data on the server, using context as a filtering mechanism; and
- **Client Application Development:** A client application was written, which simulated the mobile Web browser and invoked the XML Web Service to fetch relevant data from the Server. based on the user-context.

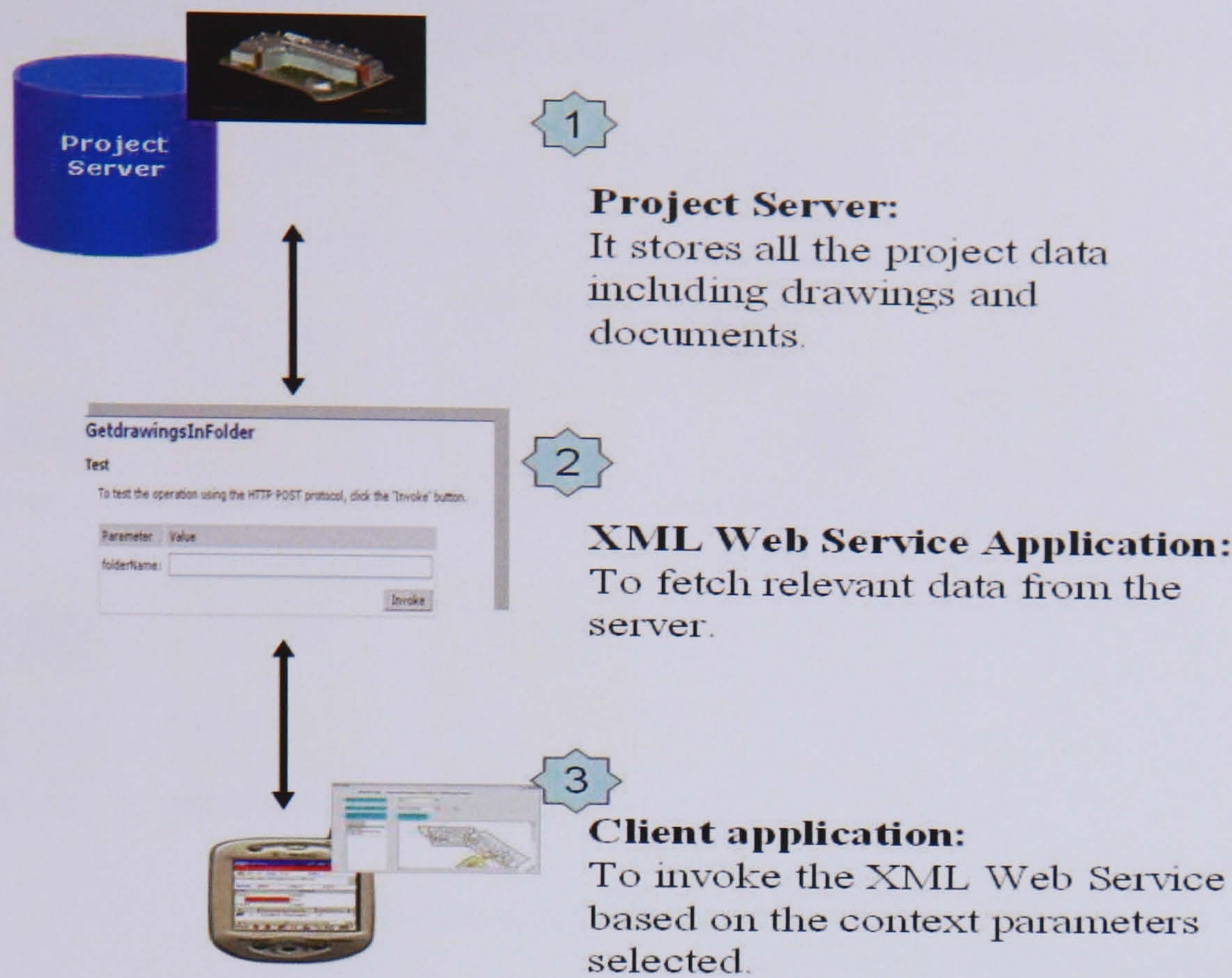


Figure 7-15: Key Steps in Implementation

The key steps in the implementation are explained in more detail below.

7.5.1. Server Application Development:

Microsoft's IIS (Internet Information Services) server was installed on the local machine (a Pentium 4-1.8GHz Notebook). A directory was created in the service root folder (Figure 7-16) of the server. This directory simulated the project database and contained all the project data such as drawings and documents. Data contained within the service root folder was accessible over the World Wide Web.

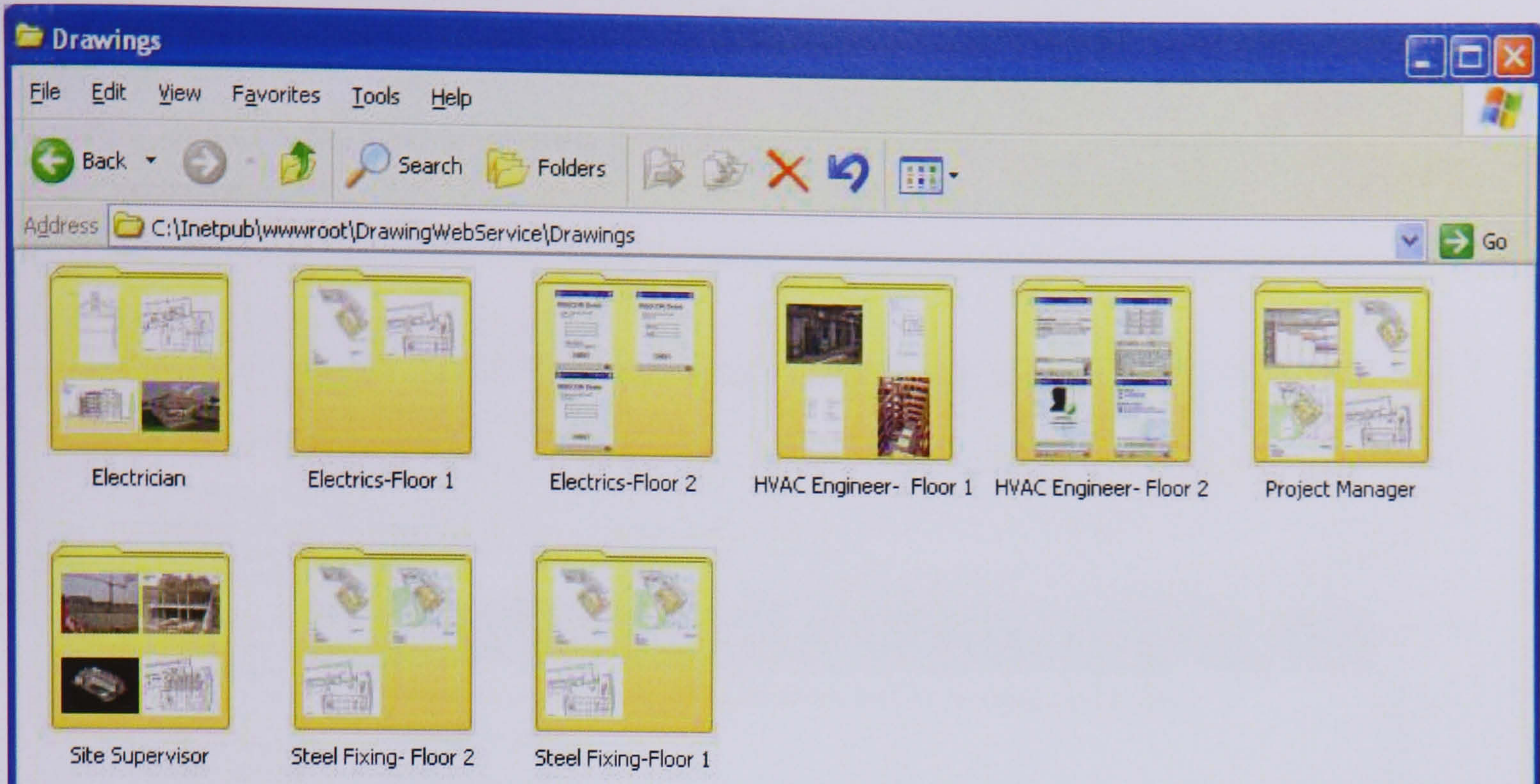


Figure 7-16: Drawings directory in root folder of IIS

7.5.2. XML Web Service Development

The VisualStudio.net development environment provides an ASP.NET template for XML Web Services development. It was used for the creation of the Web Services. A key feature of Web Service technology, as discussed in Chapter 4, is that it can be invoked from within a computer program or by explicit human input. In this implementation, the Web Service was invoked from within a program, as a result of the user selecting a particular value in the combo-box (refer to Fig 7-20). However, it is possible to write programs to invoke the Web Service programmatically. For the programming task in this implementation, some of the code was adapted from Watson and Bustos (2002). Two key Web Service methods were defined.

- **getDrawingFolders():** This method returns the name of all directories on the server; and
- **getDrawingsInFolders():** It returns all the files within a specified directory.

Running the Web Service from the VisualStudio.net environment, opens the browser, with the links to the two available Web Services methods i.e. `getDrawingFolders` and `getDrawingsInFolder` (Fig 7-17).

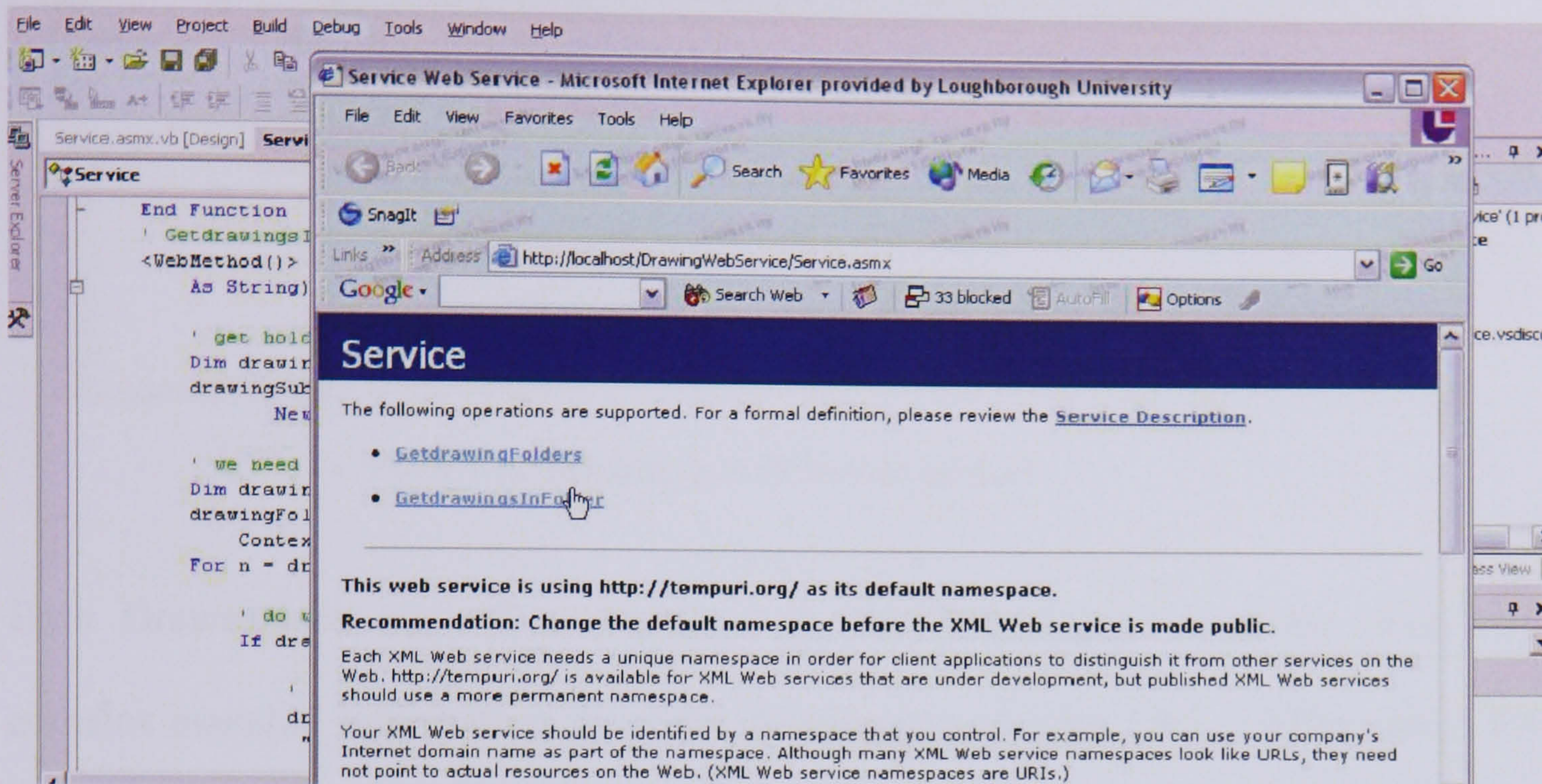


Figure 7-17: Starting the Web Service from the Development Environment

As the second Web Service method (i.e. `getDrawingsInFolders()`) builds on the first one (i.e. `getdrawingFolders()`), only the second method is illustrated in detail here. The `getDrawingsInFolder()` method takes the folder name as an input parameter and return an array of drawings from the folder. On clicking `GetdrawingsInFolder` link (Figure 7-18), the user is prompted to enter the name of the folder. Entering the name of the folder (i.e. `Electrics-Floor 2` in Figure 7-18) and invoking the Web Service, returns an XML file containing a description of files contained within the specified folder (Figure 7-19). In Figure 7-19, the Web Service was invoked manually by specifying a specific folder whose drawings need to be accessed. However, in the final implementation (Section 7.5.3), this method was invoked from within a client program by the selection of a particular context parameter value in the combo-box (Figure 7-20).

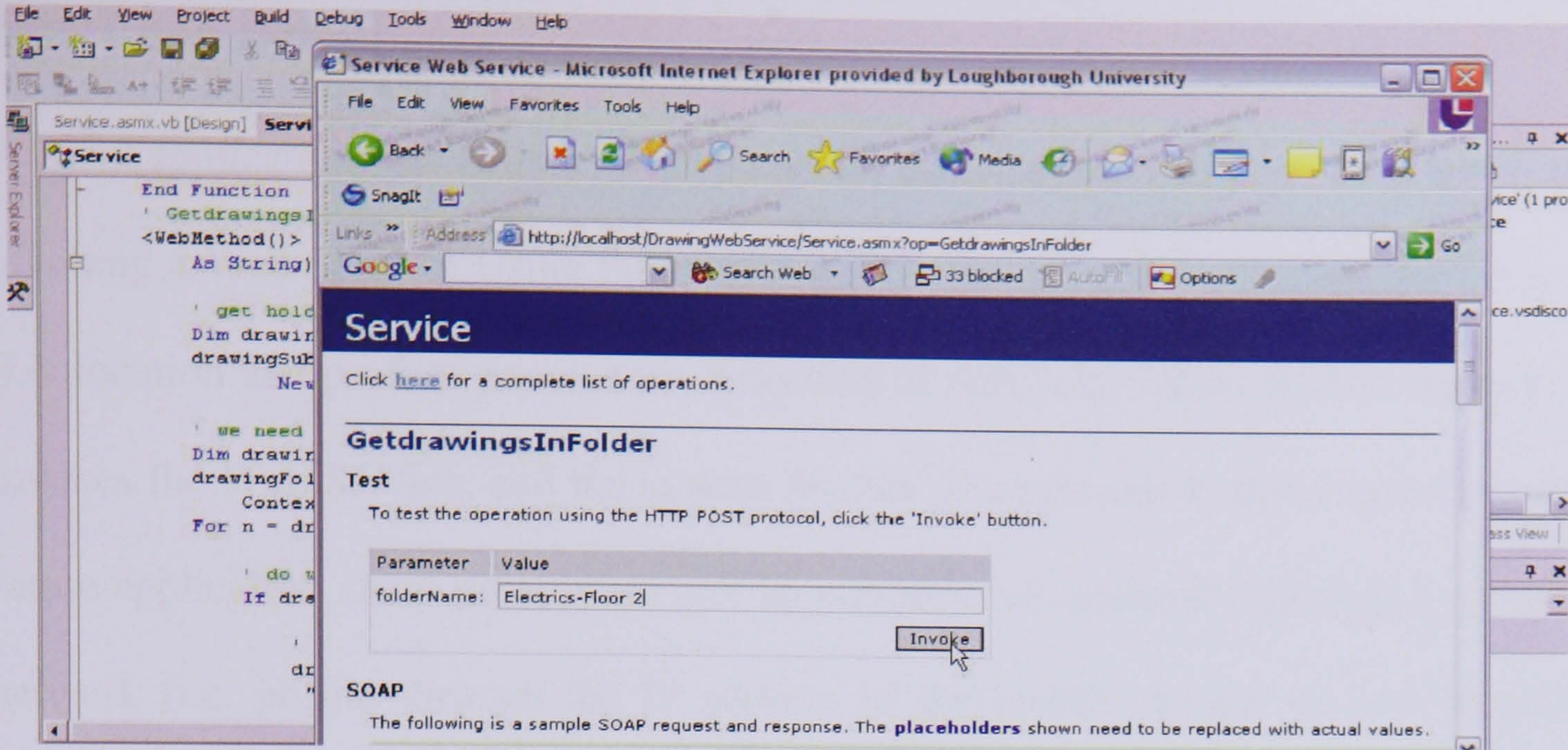


Figure 7-18: Invoking a Web Service Method

Each DrawingInfo tag (<DrawingInfo>) in the Web Service response (Fig 7-19) contains essential information about the drawing (e.g. Name, URL, Folder name, File size, File date, Image Format). To achieve this functionality, a DrawingInfo class was previously defined (Box 7-4), to describe the key features (such as Name, URL, Folder name, Image format) of the project data held on the server.

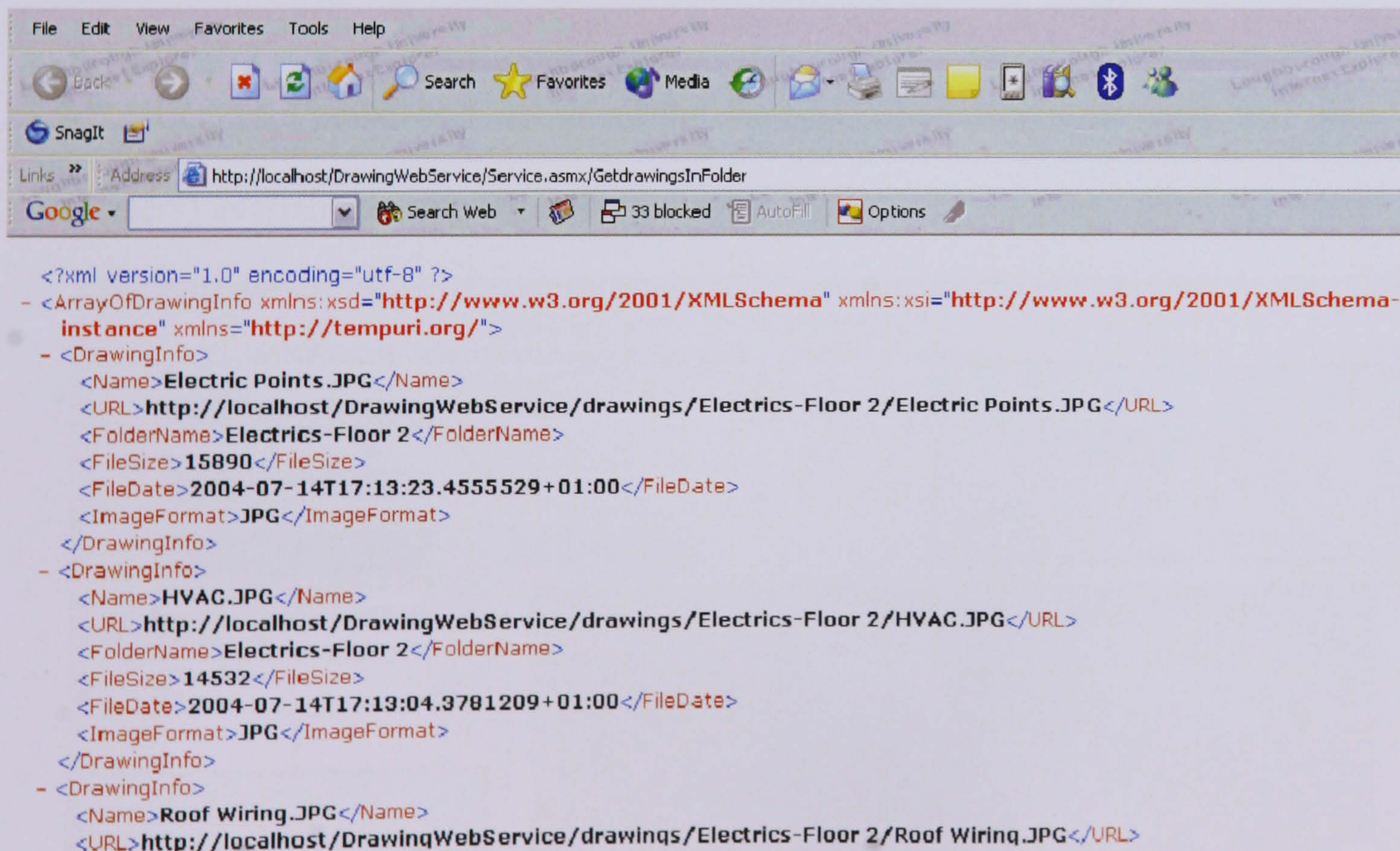


Figure 7-19: Web Service Response

7.5.3. Client Development

A client application was written to fetch context relevant data from the Web server, by invoking a Web Service. Using the client application, a user specifies his/her context (i.e. location and profile) parameters. Selection of particular values in the combo box invokes the Web Service, and the system fetches data relevant to this context. In any future application, these parameters will be available automatically through a wireless network (i.e. profile through the IP address of the mobile device, or user location through the tracking system). This will allow relevant data to be retrieved automatically, without the user specifically having to specify the context, as is the case in the current implementation.

The client application was written using “Windows Forms”, in VisualStudio.net environment (Fig 7-20). It displays data from the IIS Server (Section 7.4.1.) using XML Web Services, as defined in Section 7.4.2. To use the XML Web Service from the client application, Web Services Definition Language (WSDL) was used. The WSDL document contains a list of all the methods (including their input and output parameters) available on the Web Service (Fig 7-21).

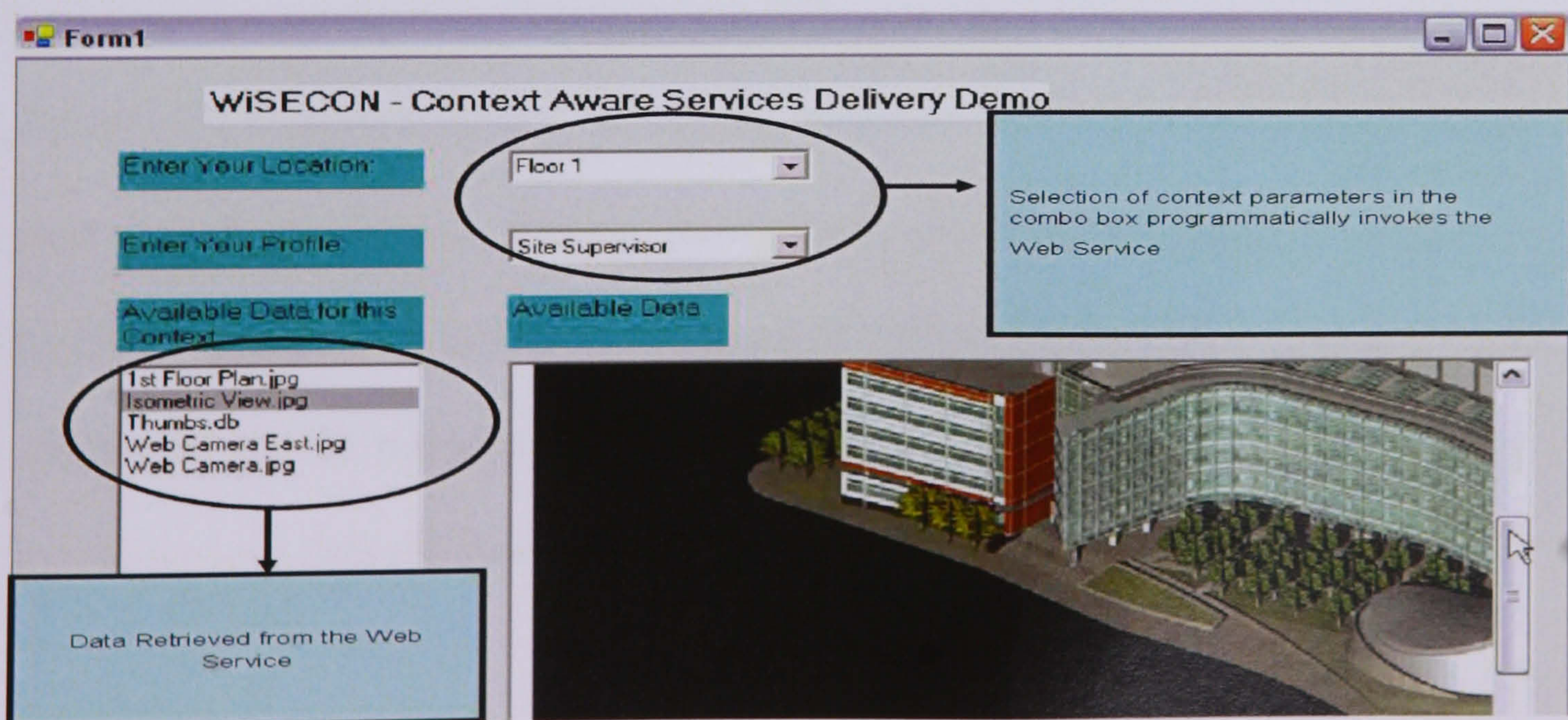


Figure 7-20: Client Interface to display Context Relevant Data

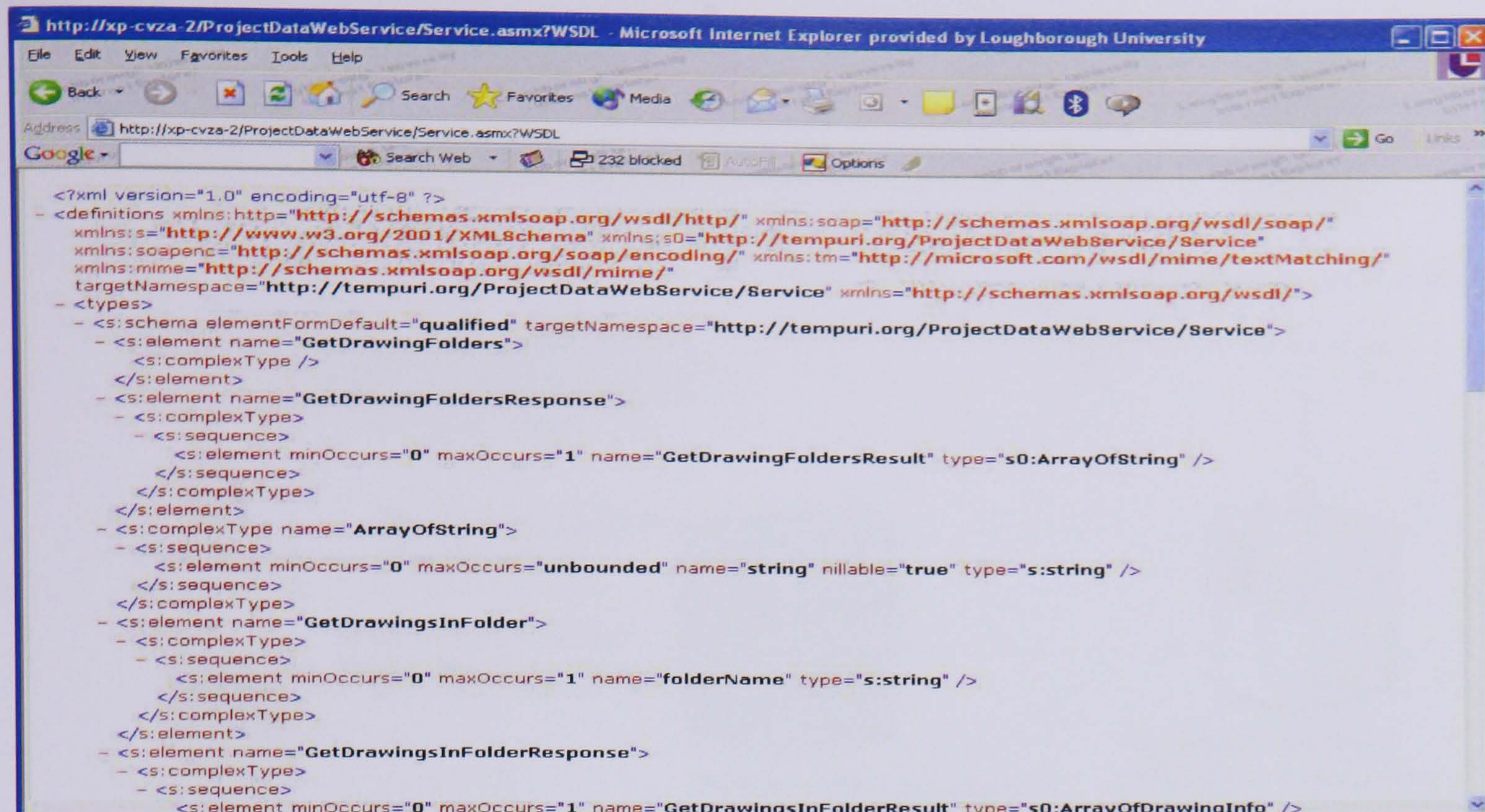


Figure 7-21: WSDL Document of Drawing Web-Service

In the client interface development, a Web reference was added to the client application. Instances of this Web reference were then used to Web Service methods as defined in Section 7.5.2. Initially a connection was made to the previously created Web Service (getDrawingsInFolder), by creating a Service object. Changing the values in the combo box invoked the Web Service and the list of files in the folder was updated.

Although in the aforementioned implementation, context parameters were hard-coded by the users, in any future application, it will be possible to capture these parameters through the wireless network (e.g. user profile from the mobile device IP address, user location from the Positioning Engine, user current task from integration with project management application). Based on the captured context parameters, a context broker can determine list of relevant data and invoke a Web-service (as defined in this section) to retrieve data relevant to the user's existing context (Fig 7-22).

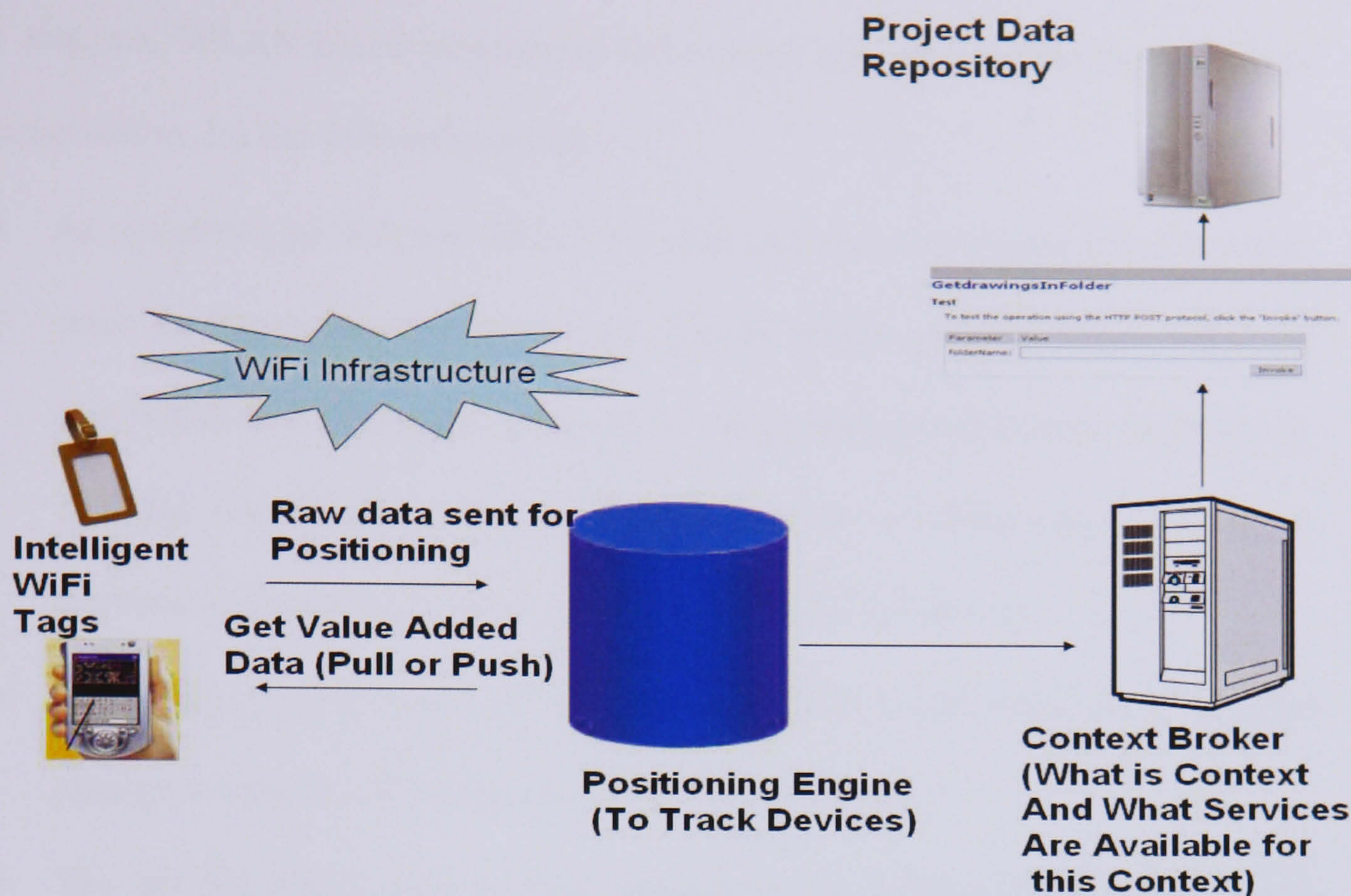


Figure 7-22: Delivery of context-relevant data using Web Services

7.6. Implementation of Tracking Sub-System

The tracking use-case (Section 6.8.6) describes the process by which the real time location of equipment and site personnel can be determined. As the focus of this implementation is primarily the built environment, outdoor and long range positioning technologies such as the Global Positioning System (GPS), were not considered in the implementation of this use-case, as they provided poor accuracy within indoor environments. Earlier in Table 3-2 and Table 3-3, various location tracking technologies were benchmarked against a set of criteria. Notwithstanding the subjectivity involved in ranking different positioning technologies as used in the aforementioned tables, it is reasonable to assume that Bluetooth and WLAN technologies will suit the prototype implementation. A key reason is their ability to track and push information to a WLAN/Bluetooth enabled Pocket-PC device, which is the main development platform being used for the prototype implementation. In the

final analysis, WLAN-based positioning technology was adopted for the prototype implementation, for the following reasons:

- As the prototype will use WLAN for data and voice communication, it makes sense for the same wireless network to track people and equipment and to get their location information. There is no additional infrastructure requirement. Thus the overall cost of WLAN-based technology tracking implementation is the lowest, compared to other options considered in Table 3-2.
- An accuracy of 1 metre, as offered by WLAN-based positioning, is good enough for the requirements of most on-site operations.
- The WLAN positioning product considered was Ekahau Positioning Engine (Ekahau, 2005), which provides a comprehensive Java-based API, that allows for easier integration of the positioning information with other applications.
- There is no proprietary hardware involved.
- A WLAN provides a considerably high bandwidth compared to Bluetooth. WLAN IEEE 802.11g standard support a bandwidth of up to 54 Mbps, whereas bandwidth supported by Bluetooth network is close to 1 Mbps.

Based on the above analysis, the WLAN-based tracking system from Ekahau (Ekahau, 2005) was chosen. The Ekahau positioning engine is a software application, which operates over existing WLAN networks. It makes use of the signal strength to determine the actual position of the target device, and then reports the tag coordinates, area, direction and speed within the WLAN coverage area. It consists of the following software components (Fig 7-23):

- **Ekahau Client™** is a small program that runs on a WLAN enabled client device (PC laptop, PDAs, Wi-Fi Tag, etc.). This client programme sends positioning information to the positioning server.
- **Ekahau Positioning Engine™** runs on a desktop PC or server and calculates the client device location. The server provides location coordinates and relevant information to other applications through a Java-based API.
- **Ekahau Manager™** is an application for recording the calibration data for a positioning model, tracking client devices on a map, and analysing the positioning accuracy.

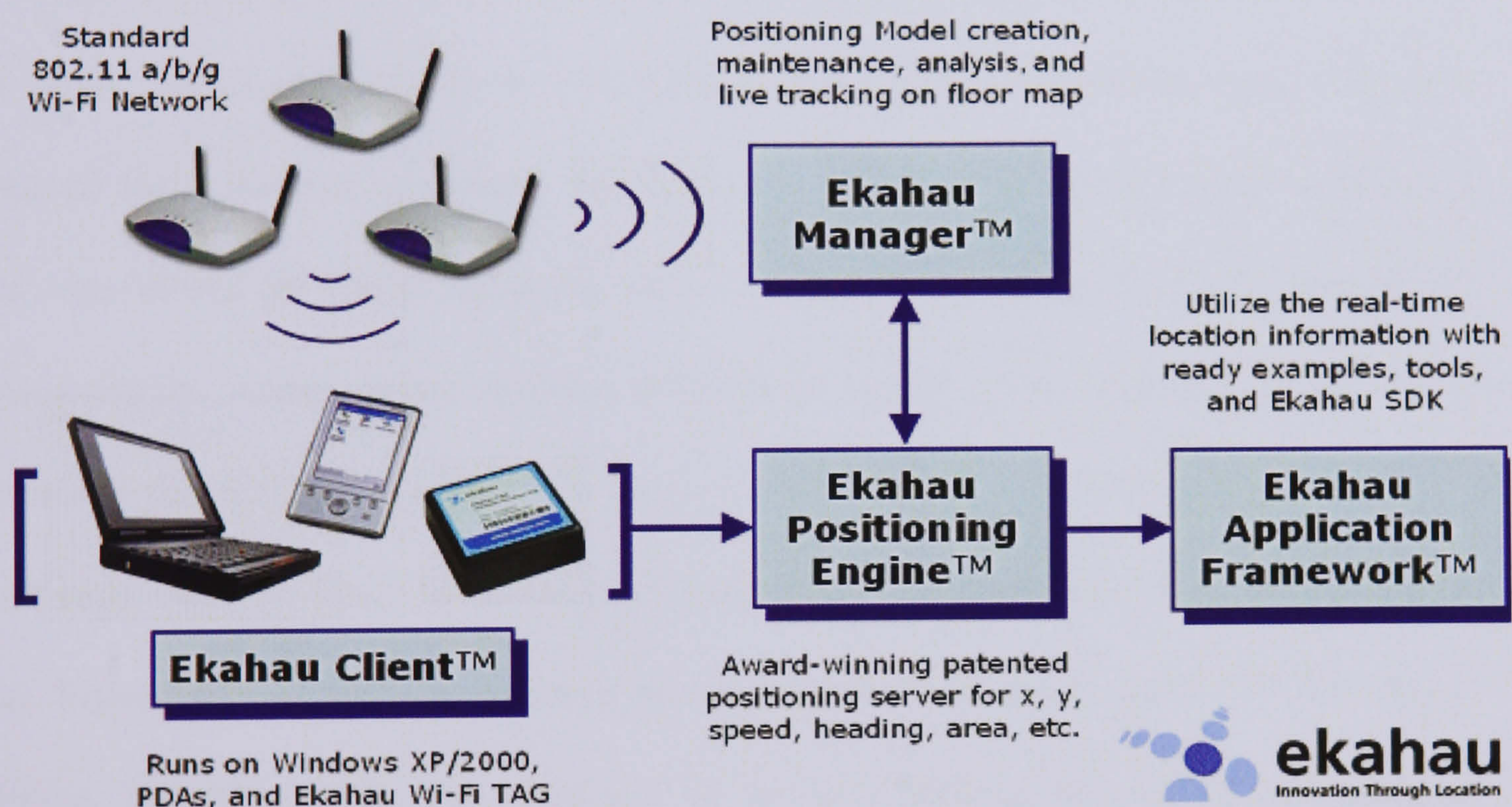


Figure 7-23: Ekahau Software Positioning Engine (Ekahau, 2005)

For the implementation objectives, an area at Loughborough University (including a research room of size 12.38 * 6.47 metres and an outside car-park) was simulated as a construction site. Four logical areas were defined within the simulated construction site, including a site office, site warehouse, a walking track and site operations area (Fig 7-24).

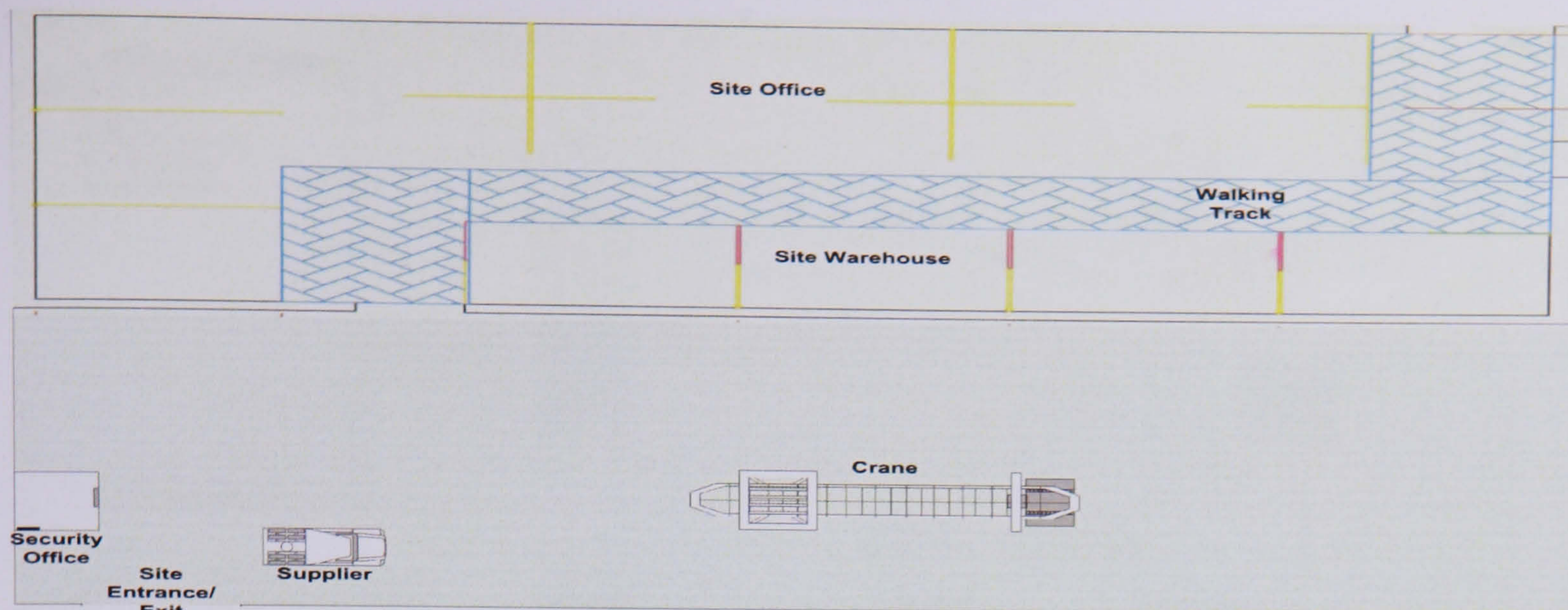


Figure 7-24: Simulated Construction Site

Using the Ekahau's manager application, calibration was undertaken. This involved walking around a particular point on the floor map and recording signal strengths for the point. Measurements were taken every two steps. A similar procedure was repeated for a number of points. When all the points were recorded, the calibration data was stored in the positioning model. The positioning engine compared the measurements made during runtime with those stored in the positioning model, to determine the real time position of the user. The object's location is updated after a fixed time interval. Once the location is calculated, the position is then shown on the map. Figure 7-25 shows the tracking of a notebook (local-host) and a WLAN tag (IP Address 192.168.1.101). An accuracy of up to 2 metres was achieved using the system. Figure 7-26 shows how tracking information can be used to deliver various value-added services on the construction site. Using the interface, it is possible to query the system using various search strings (e.g. device type and area, etc). Using a positioning engine, a mobile worker can obtain a map-based navigation from his/her current location to the target object.

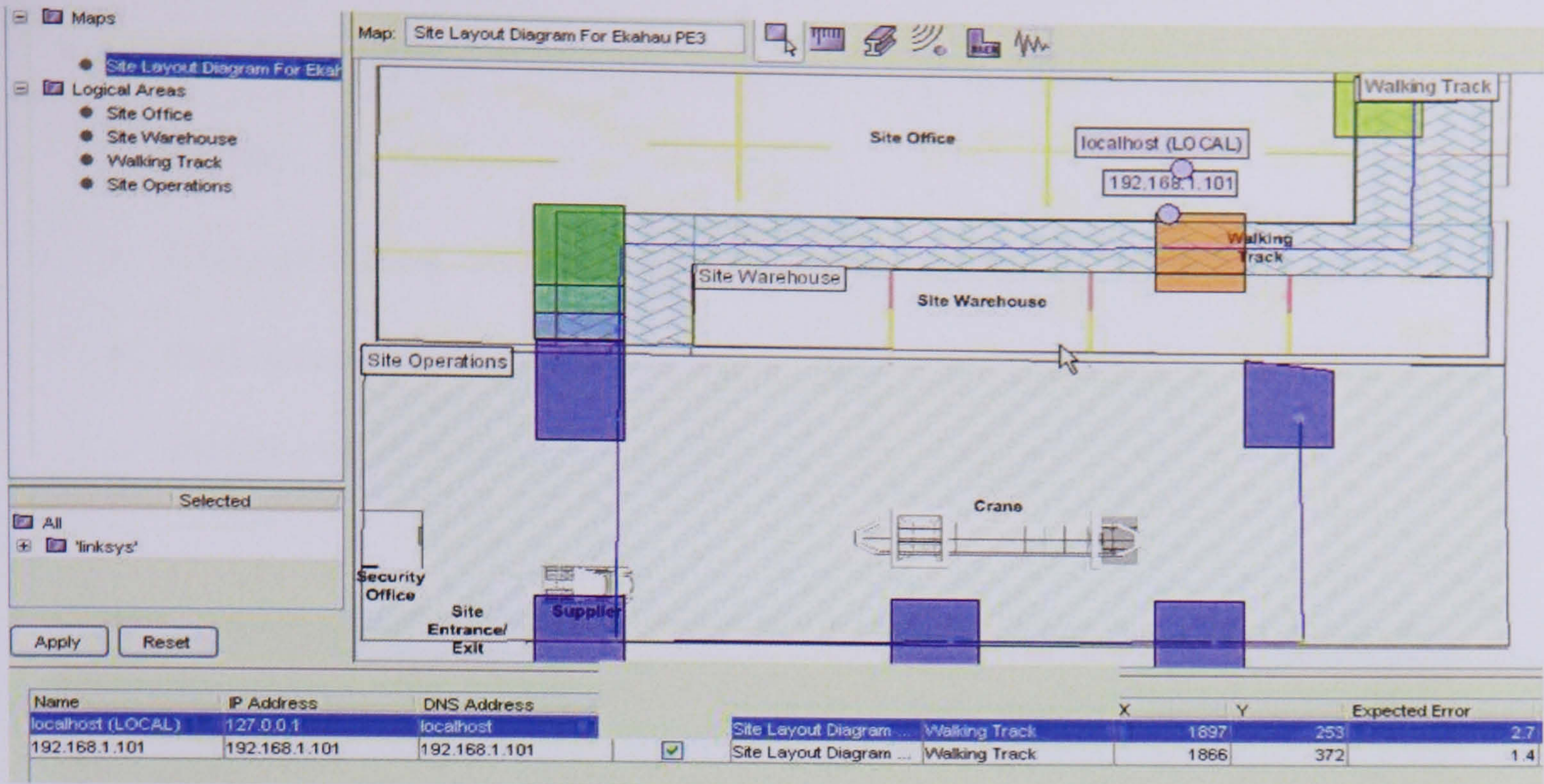


Figure 7-25: Tracking a notebook device and a W-LAN tag

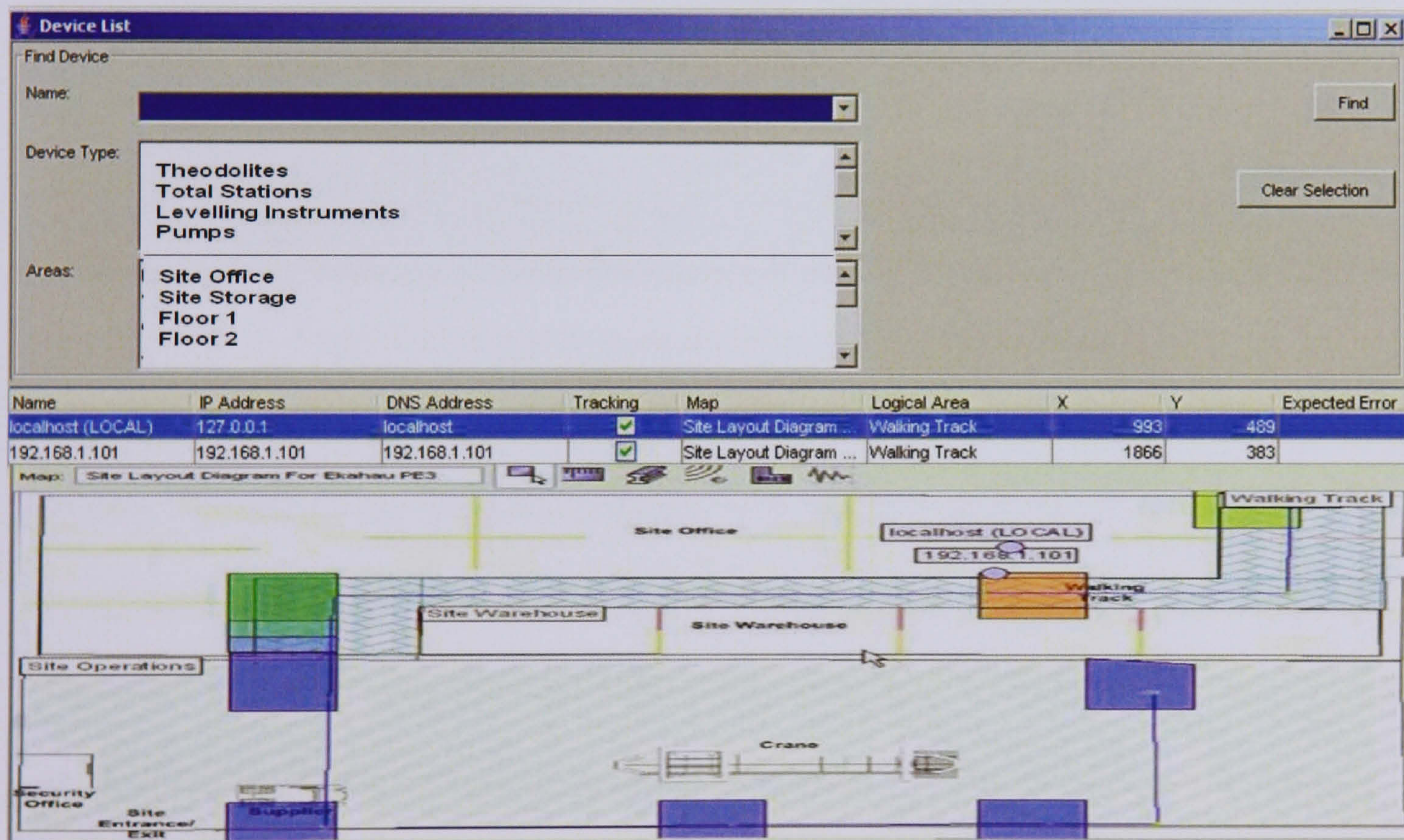


Figure 7-26: Using Tracking Information for Locating Tools

Using the Ekahau positioning engine’s Java-API, it is possible to retrieve positioning data from the positioning engine. Figure 7-27 shows the command line interface of a Java program, indicating all the devices currently being tracked by the positioning engine. Methods used in the subsequent programs include:

- TrackDeviceList() method provides a list of all the tracked devices and tags;

- TrackEachDevice() method provides real time location of each device being tracked;
- GetLogicalArea() method shows the current logical area of the user; and
- GetLocationContext() method returns the context information linked to the logical area.

```

C:\Program Files\Ekahau\Positioning Engine 2.1\sdk>java -DengineAddress=localhost
-t -classpath lib/sdk.jar;classes examples.ShowDeviceList
0 [Connection] INFO engine - Engine client message connection open: localhost
6159 [main] INFO engine - Using Database Server at localhost
6229 [DBConnection] INFO engine - Database client connection open: localhost
Device list:

MACADDRESS: 00:02:2D:87:D3:80
DNSADDRESS: 192.168.1.100
IPADDRESS: 192.168.1.100

6349 [DBConnection] INFO engine - Database client connection closed: localhost
6359 [Connection] INFO engine - Engine client message connection closed:localhost
st

C:\Program Files\Ekahau\Positioning Engine 2.1\sdk>

```

Figure 7-27: Tracking all the devices within the WLAN network

Figure 7-28 shows the run time interface of a tracking program, showing real time coordinates of a PDA. It is possible to develop similar programs, which track user location coordinates, and generate appropriate warnings, for example if a user enters an unauthorised area. Similarly, location awareness can be used to deliver context-specific data to the users.


```

C:\Program Files\Ekahau\Positioning Engine 2.1\sdk>java -DengineAddress=localhost
t -classpath lib/sdk.jar;classes examples.SimpleTrackExample 192.168.1.100
0 [Connection] INFO engine - Engine client message connection open: localhost
6059 [main] INFO engine - Using Database Server at localhost
6129 [DBConnection] INFO engine - Database client connection open: localhost
Fri Jul 23 09:42:54 BST 2004 Location for the device is X:1945.9171075789404
Y:370.8223722433619
Fri Jul 23 09:42:56 BST 2004 Location for the device is X:1934.0672931410072
Y:387.8366580307743
Fri Jul 23 09:42:58 BST 2004 Location for the device is X:1962.2066346721351
Y:408.63199870733007
Fri Jul 23 09:43:01 BST 2004 Location for the device is X:1957.1469696087136
Y:422.65079685007294
Fri Jul 23 09:43:03 BST 2004 Location for the device is X:1954.727455869637
Y:424.0507285079493
Fri Jul 23 09:43:05 BST 2004 Location for the device is X:1954.2075330844234
Y:422.4033455985403
Fri Jul 23 09:43:06 BST 2004 Location for the device is X:1936.2644912854526
Y:421.51549871735483
Fri Jul 23 09:43:08 BST 2004 Location for the device is X:1976.500365677852
Y:408.5451569650232
Fri Jul 23 09:43:10 BST 2004 Location for the device is X:1902.2133348059238
Y:398.33704350350433
Fri Jul 23 09:43:12 BST 2004 Location for the device is X:1939.6318338503304
Y:397.2250078300095
Fri Jul 23 09:43:15 BST 2004 Location for the device is X:1972.504584653922
Y:415.0729407376138
Fri Jul 23 09:43:17 BST 2004 Location for the device is X:1960.9105139582487
Y:426.92078293137826
Fri Jul 23 09:43:19 BST 2004 Location for the device is X:1935.7469241855006
Y:424.58015672462193
Fri Jul 23 09:43:20 BST 2004 Location for the device is X:1955.1973645685266
Y:419.7355802643183

```

Figure 7-28: Tracking real time coordinates of a device

This implementation has demonstrated the use of an existing WLAN network for real-time tracking purposes. A key advantage of using a WLAN-based positioning engine is that it has considerably less infrastructure requirements, compared to other location determination techniques such as Global Positioning System (GPS) and other real time location tracking systems. This makes it affordable for deployment in a site environment. Also, it is appropriate for use within the built environment.

7.7. Implementation of Voice over IP and Instant Messaging Sub-System

The real time communication and instant messaging use-case (Section 6.8.7) described the process by which a mobile worker can engage in voice communication and instant messaging with the colleagues, using existing wireless network. To implement the use-case, an off-the-shelf Internet telephony product, Skype (Skype, 2005) was used. A trial was run to use VoIP over a Wireless LAN network. Although there was background noise, the quality of voice was good. Figure 7-29 (a) shows main interface of the Skype software. Whereas in Figure 7-29 (b), use of the software for asynchronous communication, such as instant messaging is shown.

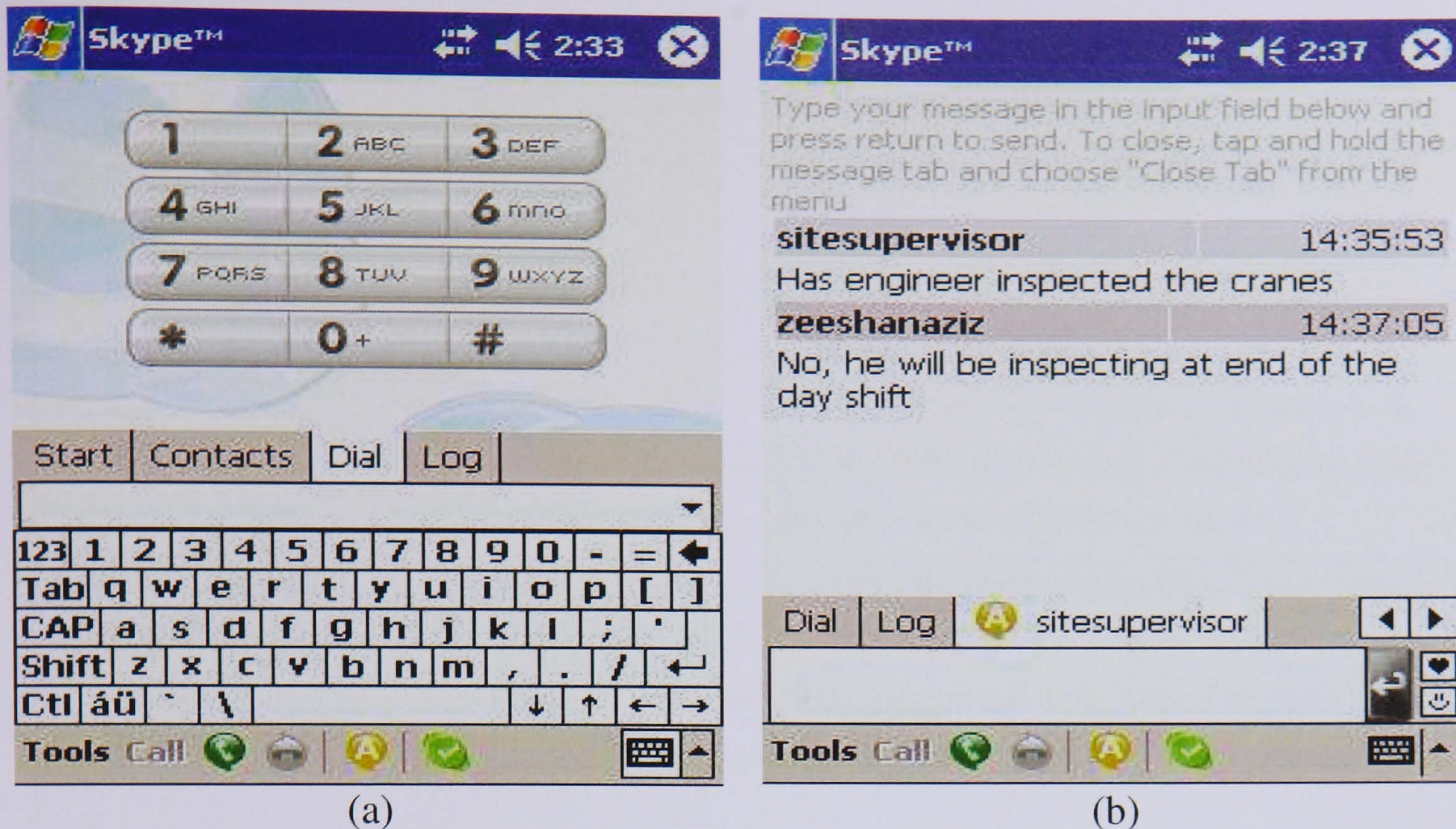


Figure 7-29: Calling VoIP (A) and Conventional Telecom Network Users

This implementation demonstrated the use of an existing on-site wireless network for voice and instant messaging support. It is possible that in future, a single mobile device would serve both the data and voice needs of mobile workers. Capability of a Pocket-PC like device to serve various information needs of mobile workers may drive its uptake.

7.8. Discussion and Summary

This chapter has presented the prototype system which was designed and implemented to satisfy the design goals as identified in Table 6-2. Table 7-2 presents a summary of how the prototype satisfies the design goals.

Table 7-2: A Comparison of Design Goals and the Prototype Implementation.

Design Goal	How it was satisfied in the Prototype Implementation?
Access to Highly Specific Data On As-Needed Basis	<ul style="list-style-type: none"> • Section 7.3 demonstrated the ability to deliver information (i.e. task-list) to mobile workers based on their profile. • Section 7.5 demonstrated the ability to push project data to mobile workers based on their context and location. • Ability to track a person or an object to map physical activities on-site to virtual domain for better understanding of the context of user activity on the construction site was shown in Section 7.5.
Real Time Project Management Support	<ul style="list-style-type: none"> • The Prototype demonstrated the ability to provide real-time project management support by enabling mobile workers to update tasks and project management plans in real time. Also, it provided them with real-time project information by intelligent interpretation of their context.
Provision of Communication Support for mobile workers	<ul style="list-style-type: none"> • The Prototype enabled mobile workers to communicate with project teams through voice and instant messaging. Communication can be both intra and inter-site.
Process Automation Needs	<ul style="list-style-type: none"> • The Prototype demonstrated the ability to automate various construction tasks such as task allocation to workers, ability to update project management plans in real-time from the point of work, automation of inventory- logistics process and ability to delivery context-relevant data, thereby eliminating the need for paper-based drawings.
Ubiquitous Intelligence Support	<ul style="list-style-type: none"> • The application of tagging technologies (Section 7.3 & 7.5) illustrated how tagging technologies can possibly be used to bring intelligence to the construction site environment and automate the information flow.
Need to address interoperability/ Integration/ Scalability	<ul style="list-style-type: none"> • Use of XML Web Services technology (Section 7.4) demonstrated how XML-based open standards can possibly be used to integrate disparate applications. • The prototype was built using a component based approach, thereby increasing flexibility and scalability.
Need to support the decision making process	<ul style="list-style-type: none"> • Context-aware information provision (Section 7.4) can be used to provide timely and relevant information to facilitate the decision making process.
Usability	<ul style="list-style-type: none"> • Usability issues were considered in design of the prototype system. For instance, on the main application interface (Fig: 7-3) an icons based approach was used where mobile worker only needs to click on a particular icon to use an application. Design of each sub-system was done, so as to minimise the task of data entry (e.g. Fig 7-5 and

Design Goal	How it was satisfied in the Prototype Implementation?
	7-14). A tab-based approach was used to ease the process of navigation through the application (e.g. Fig 7-15).
Tangible Benefits and Cost Reduction	<p>The prototype implementation demonstrated tangible benefits and possible cost-reduction potential for the Construction Industry in the following ways.</p> <ul style="list-style-type: none"> • The prototype used WLAN-based network to provide mobile workers with a number of value-added services such as tracking, access to corporate networks, voice and instant message support. Using the same wireless network for a number of different services may bring in tangible benefits and cost reduction, compared to existing approaches which rely either on cradle-based synchronisation (not real-time) or telecom network-based real time connectivity (thereby incurring recurring costs of using telecom infrastructure). • Prototype demonstrated tangible benefits of context-aware information delivery technologies in different construction scenarios. Measure the cost-saving potential of the prototype implementation is considered beyond the scope of this work. However, as the prototype rely on open-standards technologies (e.g. WiFi, XML Web Services, XML Schemas), the cost-reduction potential is assumed to be high.

It can be seen from Table 7-2 that most of the features necessary to satisfy the design objectives were satisfied in the prototype. The next chapter discusses the evaluation of the prototype system. The next chapter presents the results of prototype evaluation.

Chapter 8: System Evaluation

8.1. Introduction

Chapters 6 and 7 presented the design and implementation of a prototype system based on end-user requirements identified in the scenario analysis process (Chapter 5). However, with context-aware computing being an emerging engineering domain, the prototype design and implementation encapsulated an educated guess of what the correct system behaviour should be. Thus it is essential to perform a thorough system evaluation to test the system design and functionality and to prove relevance of implementation to the construction industry's needs. As identified by Miles et al (2000), to develop and evolve useful software tools, it is important that engineering researchers subject their systems to rigorous evaluation procedures by potential users. It is only by such means that the strengths and weaknesses of various techniques can be truly evaluated. This chapter describes the evaluation objectives, the evaluation method utilised and an analysis of the evaluation results.

8.2. Evaluation Objectives

According to Miller and Funk (2001), the two key dimensions of evaluation are validation and verification. Validation refers to whether or not the system has been built and performs as specified. It is an evaluation of an as-built system against the requirements and subsequent design. Verification refers to whether or not the system provides the benefits intended. According to IEEE specifications, verification and validation should strive to ensure that quality is built into the software and that the

software satisfies business functional requirements (IEEE-1012, 1987). Paek (2001) suggested four typical basis for evaluation. These include:

1. To identify factors in the system that can be improved;
2. To provide an accurate estimation of how well a system meets the goals of the domain task;
3. To allow for comparative judgments of one system against another; and
4. To discover tradeoffs between factors.

Given the current research context, the first two of the aforementioned objectives are considered very relevant while the last two are not considered particularly relevant. The first objective (i.e. to identify factors in the system that can be improved) is important to identify possible shortcomings of the prototype system/implementation approach. Similarly, the second objective (i.e. to provide an estimation of how well a system meets the goals of a domain task) is considered important to seek user feedback on issues related to the prototype's appropriateness and relevance to the construction industry's needs. The third objective (i.e. to allow for comparative judgement) is not considered relevant because the innovative aspects of the prototype implementation means that there is little in the construction industry to benchmark the system against. Also, the prototype employs various emerging technologies such as Web Services, WLAN-based tracking, VoIP and context-aware technologies, which are still evolving and may not provide the best trade-offs in the short term (Objective 4) compared to existing technologies, but may prove beneficial from a long term perspective. Thus, in order to truly evaluate the usefulness and the impact of the prototype, the following evaluation objectives were identified:

- To verify and validate that the system satisfies the original design goals identified from the SUNA process (Section 6.3), and to identify any additional user needs;
- To evaluate the usability and acceptability issues related to the prototype deployment, considering special deployment requirements for on-site operations. According to Miles et al (2000), usability and acceptability is an important feature in user evaluation;
- To evaluate the system's functionality, in terms of compliance with user needs;
- To obtain user feedback for further improving the system and to pinpoint any missing functionality; and
- To obtain user feedback about possible industry specific barriers and facilitators to guide any future development.

The evaluation method was explained previously in Section 2.7.6. The following sections present details about the design of the evaluation questionnaire, evaluator's screening and evaluation results.

8.3. Evaluation Process

Figure 8-1 illustrates the key steps in the evaluation process. A total of 23 evaluators participated in the process. They were first given a brief introduction to the research and a briefing about the system architecture and underlying concepts. This was important to ensure that the evaluators fully understood the implementation context and the concepts being presented. Following the briefing, the evaluators were asked to complete a questionnaire about their background. This was followed by presentation of an animated video, showing the functionality of the prototype system. Participants

were also given first hand experience of using the prototype system on a Pocket-PC platform¹. The system was set up on a single server application (running on a laptop) which was then connected to two Pocket-PC clients over the WLAN network. The prototype's functionality was explained in the context of "a day in the life of" a mobile construction worker scenario. The objective was to help evaluators see a practical application in a realistic situation and to discover issues that they might not have thought about otherwise. The presentation of the prototype system was followed by a questionnaire and a semi-structured interview, which included questions about the system's usability, relevance for the industry's needs and drivers/barriers for the industry. At the end of the evaluation session, evaluators were asked to complete a final questionnaire, to gather feedback about the prototype and the effectiveness of the evaluation process.

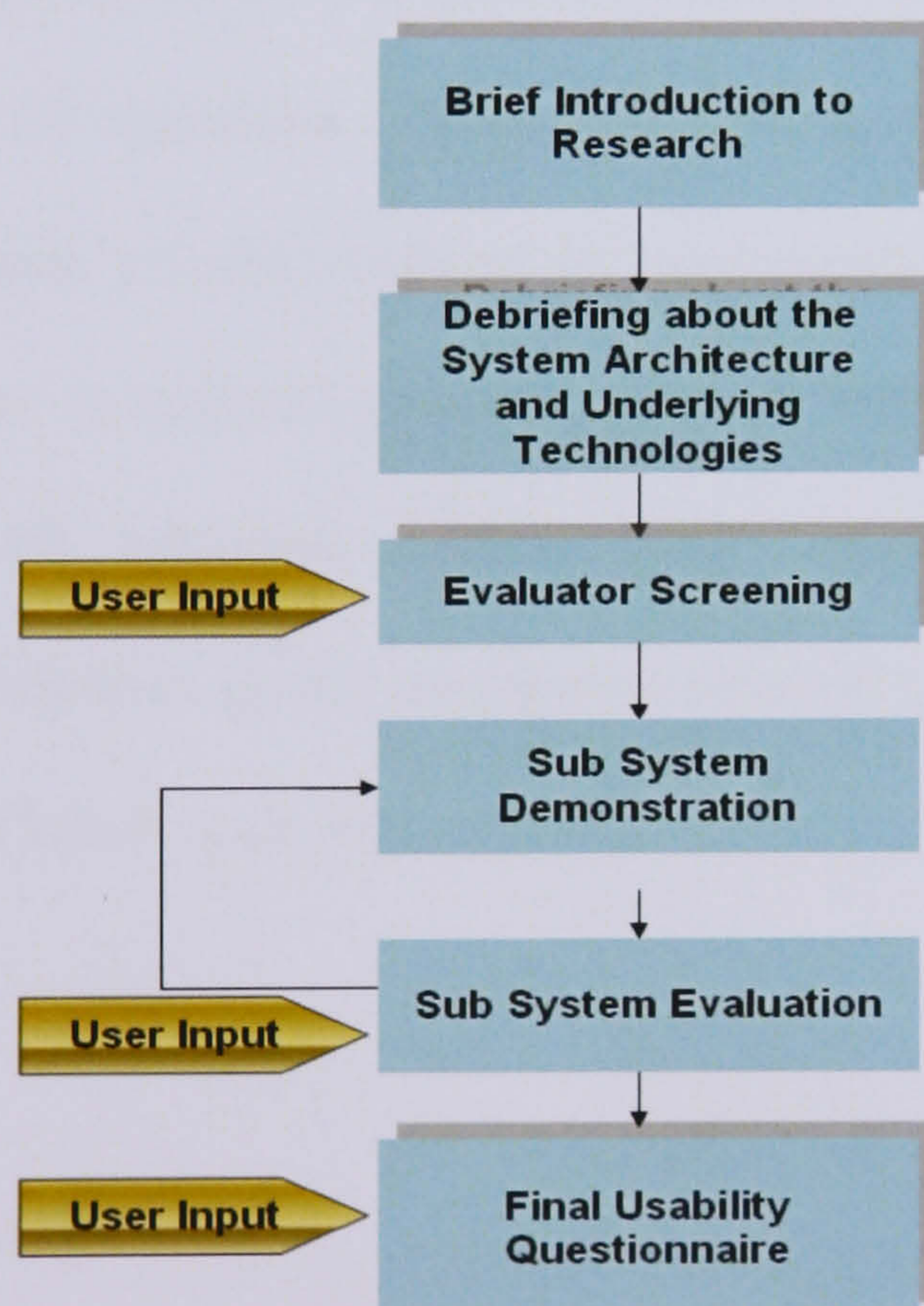


Figure 8-1: Key steps in the evaluation process

¹ In few instances, only the prototype video was shown and evaluators were not given the first hand experience. This was because a few evaluators had busy schedules and spared typically 30 -45 minutes for the evaluation process at their own offices/construction sites. Because of the time limitation and infrastructure required to set up the prototype (including Wireless LAN network and connection to server), it was only feasible to show the video of the prototype operation.

An initial questionnaire was designed, which comprised seven questions per sub-system i.e. a total of 35 questions. Questions were asked about the prototype usability, implementation approach and relevance to the industry's needs. A preliminary evaluation was conducted to trial the initial evaluation questionnaire and process, and to gather feedback for iteratively improving the prototype. Three experts from the construction industry were involved in the pilot evaluation. Evaluators complained about the questionnaire being too long and requiring too much time. It was also suggested to place more emphasis on the qualitative data collection, to seek user feedback on issues related to prototype deployment.

Following the feedback from the preliminary evaluation, the questionnaire was redesigned. The final questionnaire (Appendix C) comprised 3 questions per use case, providing a total of 20 questions. Questions were asked about the prototype's implementation approach, possible barriers to implementation and relevance to the industry's requirements. It required participants to provide feedback through a four point Likert scale with responses ranging from "strongly agree" to "strongly disagree". To avoid evaluators giving ambiguous answers (such as "neither agree nor disagree"), a five point Likert scale was not used.

8.4. Evaluator Screening

To ensure the quality of the evaluation data, it is important to evaluate the system through relevant end users (Miles et al, 2000). The key objective of screening evaluators (Figure 8-2) was to get sample data from the representative user groups. User screening was considered in the analysis of evaluation results, thereby increasing

the level of results reliability. For evaluation purposes, various stake-holders were divided into four groups. These stakeholders represented user groups who had an active interest in the successful implementation of the system. They included:

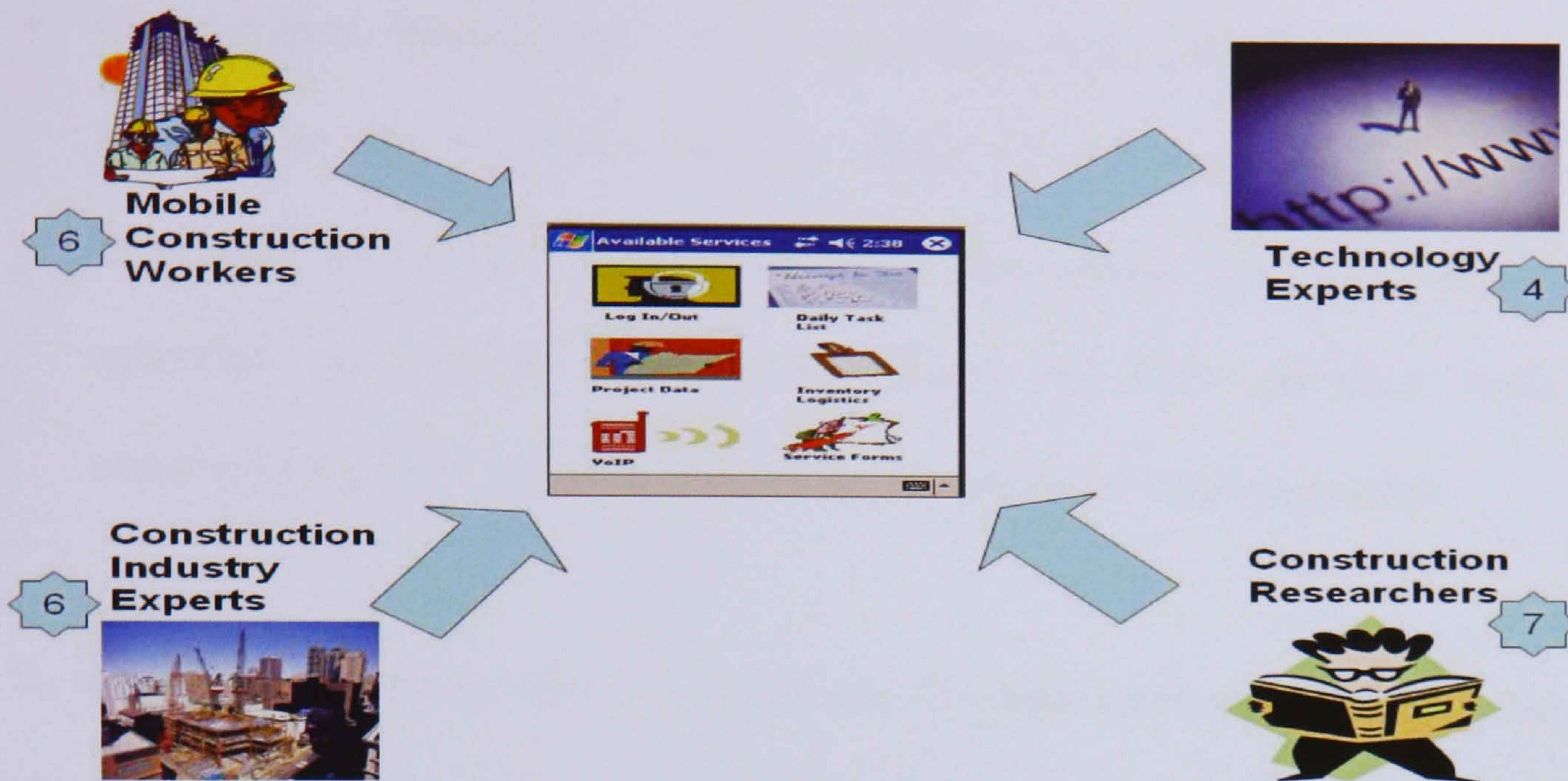


Figure 8-2: Categorisation of Evaluators²

- Mobile Construction Workers:** This group included potential end-users of the system. It was essential to have their perspective on the system because without the discipline of evaluation by end users, there is no independent metric with which to assess the suitability of a given software (Miles et al, 2000). A total of six evaluators (four project managers and two site managers) participated in this category.
- Technology Experts:** This group included experts with specialist knowledge of a particular technology domain, which is of relevance from the viewpoint of the prototype implementation. Their participation in the evaluation process was important to ensure that technology was deployed in an optimal manner. A total of four evaluators participated in this category. Their specialised domains included mobile computing, intelligent computing, ubiquitous computing and usability.

² The number shown in the octagon in Figure 8-1 indicates the number of participants in each group.

- **Construction Industry Experts:** This group included professionals who have five or more year experience of working in the construction industry. Six evaluators participated in this category.
- **Construction Researchers:** Seven researchers from ACE backgrounds were involved in the evaluation process. Three of the researchers had previous experience of on-site construction work. Researchers had knowledge about specialist area of the construction industry and their analytical skills and experience provided valuable insights for the prototype implementation.

A small scale workshop with 11 participants (7 construction researchers, 3 industry experts, 1 technology expert) was run to evaluate the prototype implementation.

While one-to-one evaluation sessions were held with those, who could not attend the workshop.

8.5. Evaluation Results

Twenty-three evaluators participated in the evaluation process during which feedback was gathered about the users' subjective evaluation on three critical issues, including:

- Prototype implementation;
- Possible barriers to implementation;
- Relevance to the construction industry's needs.

The results obtained are described in the following sections.

8.5.1. Evaluators' Feedback on the Prototype Implementation

Table 8-1 presents a summary of key issues identified by evaluators during the prototype evaluation.

Table 8-1: Evaluator's Feedback on The Prototype Implementation

No.	Evaluator's Feedback On The Prototype Implementation	Comments									
<p>1. Task Allocation and Wireless Project Management Sub-System</p>	<p>Evaluators Feedback on the sub-system Interface:</p> <p>There were mixed views about the prototype interface. While some evaluators complained that the interface was too small to view the details, others thought it was appropriate. Interestingly, all the evaluators interviewed in the mobile construction workers category said that the prototype system was easy to use compared to the existing approaches. The chart below show user-response to the question "The sub-system interface is easy enough for an average construction worker to learn and use".</p> <div> <table border="1"> <caption>Response Distribution for Interface Usability</caption> <thead> <tr> <th>Response</th> <th>Percentage</th> </tr> </thead> <tbody> <tr> <td>Agree</td> <td>44%</td> </tr> <tr> <td>Strongly Agree</td> <td>22%</td> </tr> <tr> <td>Disagree</td> <td>28%</td> </tr> <tr> <td>Strongly disagree</td> <td>6%</td> </tr> </tbody> </table> </div>	Response	Percentage	Agree	44%	Strongly Agree	22%	Disagree	28%	Strongly disagree	6%
Response	Percentage										
Agree	44%										
Strongly Agree	22%										
Disagree	28%										
Strongly disagree	6%										

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>used by another, in a few days time. Also, there is a possibility of mobile devices being stolen, and a worker using another device with a different IP address. For all such reasons, using IP address as a hook to deliver services to users is not recommended”.</p>	<p>some reasons, it may be possible to use 3G/WiMAX as a backup for real-time connectivity. Also, it is possible to change association of a user and a device through an administrative interface.</p>
	<p>Issues Regarding Automated Task Allocation:</p> <p>A number of issues were identified by evaluators regarding automated task allocation. These are described as below:</p> <ul style="list-style-type: none"> • In the prototype implementation, a simple task list was pushed to the user mobile device after a successful login. An industry expert suggested that it is important to have a mechanism to assign priority to various tasks. He said, “On-site conditions are dynamic and the priority of various tasks keep on changing with the changing project conditions. There ought to be a way to reflect changing task priorities in the task list assigned to workers”. • An industry expert commented that it will be more useful to link a task-list with the project management plan. He said this will allow richer information delivery to the user, as the user can browse through his task-list and then go to the project plan to see other details. • Another evaluator (a site manager) questioned the utility of assigning pre-defined tasks to workers. In his view, “The site environment is not like a manufacturing environment, where the tasks are much more well defined. In construction project management, oral communications are very important. During the course of the day, I speak to foremen many times, and assign them various tasks. Oral communications play a key role in task assignment. If the project manager or a site manager is not used to assigning tasks like this, the proposed system may be 	<p>During the evaluation process, evaluators expressed keen interest in the prototype, and expressed a desire to see additional features in the prototype (for instance, ability to prioritise tasks and an ability to link the task list to project management plans. Such features are useful and should be considered for any future application development. However, delivering such functionality is not within the scope of this research.</p> <p>The objective of automated task allocation is not to replace oral communications. Rather to provide additional support to mobile workers, in order to help them accomplish the elements of the project plan and to support oral</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>rendered useless. May be in larger projects, such a system can be used to replace paper-based task allocation. However, the site supervisor will still need to speak to the foreman, and assign tasks from time to time".</p>	<p>communications.</p>
	<ul style="list-style-type: none"> An industry expert had similar concerns about the utility of the wireless project management application. He mentioned "A fundamental issue is whether it is required to update project management plan from a handheld device. Update to project plans can very well be undertaken by some one sitting in the office with an access to corporate project management application. It may, very well depend on how big a site is". 	<p>Ability to update project plans from point of work will offer greater flexibility and will save valuable time.</p>
	<ul style="list-style-type: none"> A construction researcher highlighted the fact that "Assigning tasks to on-site personnel is an additional workload for the site supervisors and they may be reluctant to take it. It also means that the site supervisor will spend more time away from the site, and in front of his computer". 	<p>Any subsequent deployment of such a system needs to address such usability/acceptability concerns. It is important that the site-staff see the technology to facilitate their work, rather than to make it more complex.</p>
	<ul style="list-style-type: none"> A site manager mentioned real time connectivity as a key advantage of such a system. He commented, "In our company, we tend to use computer systems for project management and drawings, but at the site level, everything comes back to the old system. Everything comes as an instruction, from designer or from an architect. We have to wait for the instructions to turn up, before we start doing work. Everything comes as a hard copy involving a lot of paper chase. A PDA-based system will help us do things fast, it will also help us in implementing changes rapidly". 	<p>Benefits of real-time connectivity for the site-staff are obvious.</p>
	<p>Trust Issues: Another evaluator (a technology expert) highlighted potential trust conflicts arising because of the way prototype is implemented. In his view, "In current work practices, the details of work completion are recorded by site engineers. The way the prototype is implemented, there is a chance that some users (e.g. sub-contractors) may</p>	<p>It is possible to address such trust issues by setting right access permissions, so that project management application is updated only when</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>try to fool the system, by recording the work to be completed, whereas in fact, it is not. There should be a layer above to ensure that all work is inspected by the engineers before being recorded in the system as being completed".</p> <p>The need for signatures was also highlighted by a construction researcher.</p>	<p>the work is approved by an engineer. However, as mentioned before, addressing such implementation details are beyond the scope of this research.</p>
	<p>Use of Bluetooth Wireless Technology: Two evaluators raised concerns about the appropriateness of using Bluetooth Wireless Technology for the prototype implementation. Concerns included its limited range and limited data transfer rates. An industry expert also reported problems of configuring the Bluetooth devices and commented that the technology is more appropriate for office-based operations.</p>	<p>Prototype used Class 1 Bluetooth, with a range up-to 100 metres and data transmission capacity of 1 Mbps, which is considered appropriate for supporting most on-site operations.</p>
	<p>Internet connectivity issues: The prototype uses WLAN technology and Internet connection as the basis for providing real time network access. It was highlighted that the system would not work if an on-site Internet connection is not available.</p>	<p>As mentioned before, 3G/WiMAX technologies can be used as a back-up for on-site WLAN.</p>
	<p>Security Issues: Various security issues were identified by evaluators. These include:</p> <p>A. Off-line data storage: "The way the prototype is implemented, all project management data is being stored offline. If a device is lost, all project management data will be lost" (a technology expert)</p> <p>B. Need for access permissions: "As system is being made available for different type of users, it is important to set access permissions for different category of users" (technology expert).</p>	<p>A). Though off-line data storage is a valid concern, however, the other alternate is using Web-based technologies, which makes it difficult to provide a feature-rich environment on a mobile device. Thus it is a case of balancing security concerns and usability demands. Also, it is possible to protect offline</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments								
		<p>data using other security mechanisms such as encryption and biometrics-based log-in.</p> <p>B) In any real-life application, such access permissions can be easily set using existing technologies.</p>								
<p>2. Inventory Logistics Sub-system</p>										
	<p>Evaluators Feedback on the sub-system Interface:</p> <p>Of the 23 respondents, a dominant 78% (61% strongly agreed, 17% agreed) thought that the interface of the sub-system "Inventory Logistics" was easy enough for an average mobile construction worker to learn and use for daily tasks. 22% of the respondents disagreed with this opinion.</p> <div style="text-align: center;"> <table border="1" style="margin: auto;"> <tr> <td>Disagree</td> <td>22%</td> </tr> <tr> <td>Strongly disagree</td> <td>0%</td> </tr> <tr> <td>Agree</td> <td>17%</td> </tr> <tr> <td>Strongly agree</td> <td>61%</td> </tr> </table> </div> <p>The following suggestions were made for improving the sub-system interface:</p>	Disagree	22%	Strongly disagree	0%	Agree	17%	Strongly agree	61%	
Disagree	22%									
Strongly disagree	0%									
Agree	17%									
Strongly agree	61%									
	<ul style="list-style-type: none"> A technology expert suggested giving various options to users to select from, such as combo boxes or check boxes, asking the user questions such as, "Did the items arrive at the right time?", and "Were they delivered as 	<p>Given the limited display size of Pocket-PC devices, it is indeed important to minimise data</p>								

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	ordered?".	entry, in order to make application easy to use.
<ul style="list-style-type: none"> <li>• An industry expert mentioned that he found the data entry using the on-screen Pocket PC keyboard too tedious. He said, such data entry is difficult even for experienced users and if it is too difficult to use, workers will throw the gadget at the back of the truck. He suggested replacing keyboard-based data entry with other options such as combo-boxes and check-boxes. 		However, there are occasions where data input from the mobile worker may be required. Few possible options to improve user-friendliness include using voice-input, Pocket-PCs with embedded cameras or using thumb-based key-boards.
<ul style="list-style-type: none"> <li>• A site supervisor commented on the prototype implementation stating that "... You have assumed there is only one person who is responsible for receiving delivery. Yeah, you can quite easily train somebody to use such a system, having one person responsible for all goods entering the store and moving out of it. This happens in larger projects, where they have one person to manage inventory and the system is highly centralised. But on smaller sites like ours, when the delivery arrives, whoever is free will receive the delivery. It is not a specified job function". 		Such concerns reinforce the need to develop user-friendly interfaces, so that different people can be easily be trained to use the system.
	<p>Need for providing detailed data support: A construction researcher highlighted the fact that there is need to provide detailed data support for situations where a mobile worker requires information about another supplier, a previous delivery or items which are not part of the current delivery.</p>	In the prototype implementation, it was not possible to provide such a detailed data support. However, it should be a part of any future/commercial implementation.
	<p>Need to provide corrective mechanism: An evaluator (usability expert) identified lack of a corrective mechanism in the prototype as a potential source of problem. In his view, absence of such a mechanism may hinder the construction process rather thanfacilitating it.</p>	As the prototype demonstration was essentially a technology showcase, such corrective mechanism was not provided. However, it should be part of any commercial deployment.
	<p>Need to track individual items: An industry expert commented, "In your implementation, you receive bulk delivery, and use a tag to record it. Well and good. However, tracking bulk items or expensive items is not such a big</p>	In future, it is possible to use WLAN tags to track bulk items across the supply-chain (the

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>problem on sites. They usually get looked after. Tracking small items and low value products is a big issue. A bulk delivery arrives and then it is split and distributed around the site. It is the individual small items which go missing." It was suggested, that the need to track individual items can be addressed by attaching bar codes/RFID tags to each item, and then querying the items using a reader possibly integrated with a Pocket PC device.</p>	<p>advantage is that these tags do not require any additional infrastructure, assuming that WLAN is already set-up), while RFID tags can be used to track small individual items (the key advantage of RFID tags is their low cost).</p>
	<p>Need to address downstream issues:</p> <p>An industry expert emphasised the need to address downstream issues related to the tagging process such as:</p> <ul style="list-style-type: none"> • Which products to tag; • How to put the tag on the product; • Whether the building component tags should be incorporated within the building for possible use in the later life-cycle stages or removed before construction; and • Who is responsible for auditing tags. <p>He further mentioned, "It is not sensible nor does it make any economic sense to tag everything. However, there may be certain tools that may either get stolen or are in high demand, that may need to be kept track of. It is important to address such issues as they will determine whether or not a solution would work in a site environment".</p>	<p>It is important to address such issues as part of any future application. However, the key objective of the prototype implementation was to demonstrate technology potential, and addressing such downstream issues is considered beyond the scope of this work.</p>
	<p>Potential for Using Tagging System For Materials Management</p> <p>A site manager emphasised the need to use a similar system for materials management. His view was "Because we are using so many components, a lot of it gets wasted. Whether it is pilfering, or people take more than they need.</p>	<p>Tagging technologies can be used for a wide range of applications, including materials management.</p>

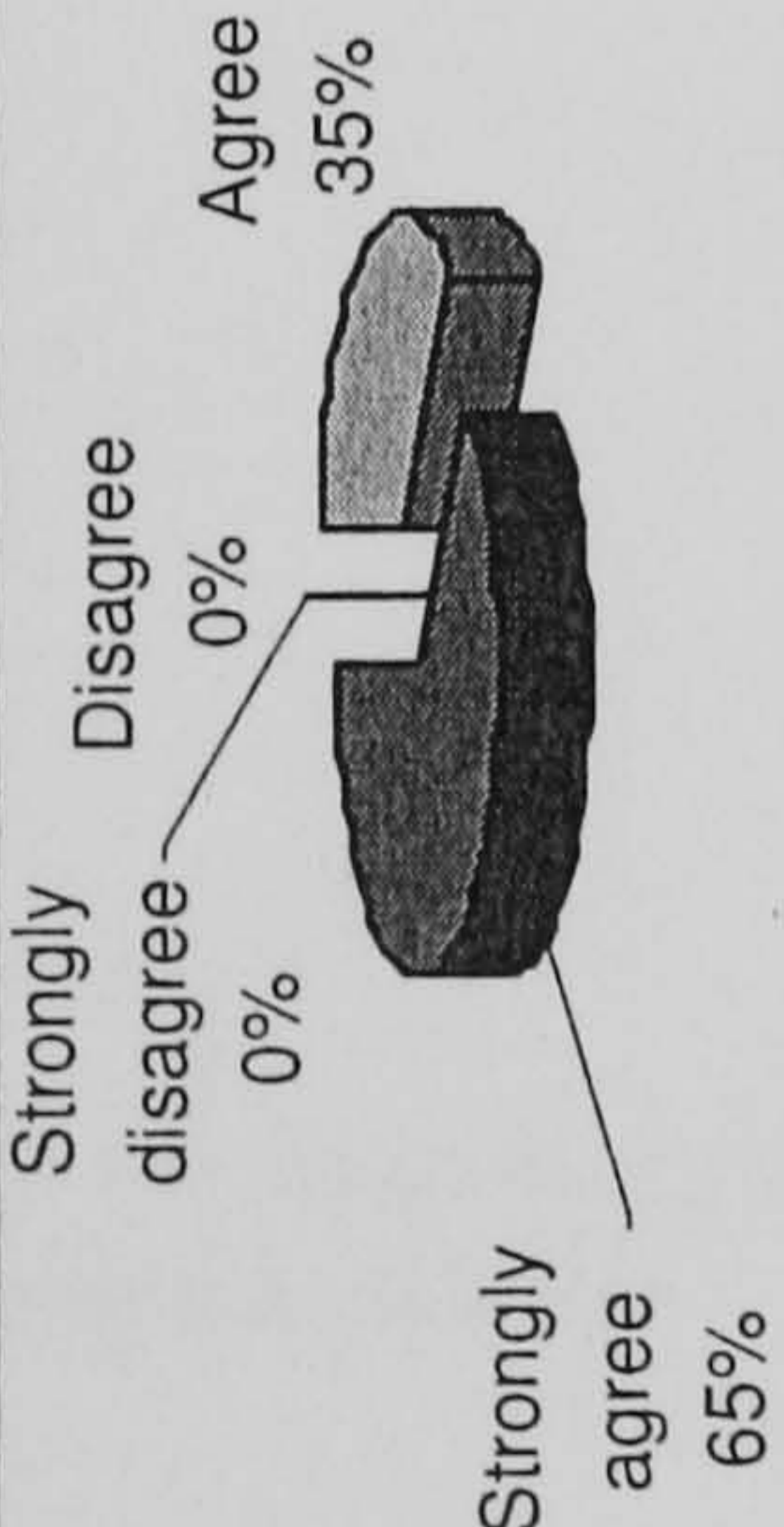
No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>They then just discard the unused material; that is where you tend to lose a lot. Such a barcode/RFID-based system can be used to control materials wastage. Also, many times inventory items go missing or are stolen. We need such a technology particularly for small projects. In larger projects, usually there is one person responsible for running the store, and resource control policies can easily be implemented. In smaller projects, there is a lot of wastage".</p>	
	<p>Security Issues: Security concerns, related to off-line data storage were raised, and it was suggested to use server-based technologies.</p>	<p>As mentioned before, it is possible to secure data off-line using biometrics-based log-in or using encryption.</p>
<h3>3. Context-aware Project Data Access Sub-System</h3>		
	<p>Evaluators Feedback on the sub-system Interface: 72% of the respondents agreed to the statement that the sub-system interface is easy enough for an average mobile construction worker to learn and use for daily tasks. 28% of the respondents disagreed with this opinion.</p> <div style="text-align: center;"> <p>Disagree 28% Strongly disagree 0% Agree 11% Strongly agree 61%</p> </div>	<p>Interface issues, related to small size of the PDA screen, were highlighted by few evaluators.</p>
	<p>Need to address other context dimensions: A technology expert highlighted the need to address other context dimensions. He said, "There is scope to address other context dimensions. I think, a more detailed study will be</p>	<p>The WiSeCon framework allows the capability to add other context dimensions.</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>required to investigate different types of contextual information required for different type of mobile work. For example, information about things like whether or not both hands of the mobile worker are free, can be useful to determine the most appropriate way to deliver information. One way to go about it would be to record the situational information as the site personnel go about their daily tasks and to note down what actions they take at a particular time. Capturing such situational data will also help to determine what sort of data will be relevant for a particular situation".</p>	
	<p>Need to Capture Context History: A technology expert commented that it is important to capture the context history, so that one can have an idea of what decisions were taken in the past for a specific situation in a specific context. Thus, if a similar situation arises at a future date, it will help to know what decisions were made in similar contexts in the past. In his view, "It is critical to model and then provide support for users across multiple activities and projects, with the history of previous projects playing an integral role in determining future actions".</p>	<p>It is important to capture context history to allow for historical comparisons and for effective knowledge management. Use of the Semantic Web technologies in the WiSeCon framework allows for effective capture and comparison of the context knowledge.</p>
	<p>Potential of Using PDA as a Drawings Backup tool: An industry expert commented that a PDA-based system may work quite effectively to back up the information on the drawings or to view specification aspects of the drawing. His comment was "If you develop a project model, a 3D or a 4D model, then it will be possible to have some sort of intelligence. So for instance, punching in a valve number may give specifications of a bolt size. Such sort of specification information can easily be viewed on the PDA. Such detailed information sometime are not on the paper copy. Such a PDA-based system could possibly be used for version control. Typically poor version control (i.e. use of outdated drawings) is the cause of a lot of rework in construction...It is possible to instigate a discipline, by which a person, before getting data (e.g. valve data, enters the part number). Based on the part number entered, the system can check to ensure that the version of the drawing the user has is the latest one. Thus accessing drawing details can work as a filtering mechanism, to ensure that the drawings are updated at regular intervals" (An industry expert).</p>	<p>As suggested, a PDA-based tool can effectively be used to back-up the information in the drawings and for version control.</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>Potential for Delivering Health & Safety (H&S) Data</p> <p>A site manager highlighted the potential for using such a system to deliver health and safety data: "...H&S file for this project has over 300 pages. Trying to find something out of it, one has to sit and read all the way through. It ends up not being used. There are separate H&S files for each project, but most of the content is the same. They put everything into it. Even the correspondence between our main office and the architects goes into it. At the end of the day, we end up with a thick stack of paper, which ends up not being used. If we use a system which tells you about all the relevant H&S information, that will make the process of finding the right information very easy".</p>	<p>As highlighted, awareness of user-context can be used to effectively deliver relevant H&S information and warnings.</p>
	<p>Need to Focus on the quicker wins for the technology:</p> <p>An industry expert suggested, "The potential of context-aware services delivery is more visible in serving the data needs of the people who usually work towards the end of the project such as HVAC engineers and other people from mechanical/electrical trades such as those who fit fire alarms and communications control work. There are relatively fewer robustness problems with the hardware, at the later stages in the project. Also, the workforce employed in the later stages is more experienced and more amenable to the new technology".</p>	<p>It is important to focus on those application scenarios which can encourage the uptake of new technologies in the construction sector.</p>
	<p>Miscellaneous Issues: Various other issues with regards to the prototype implementation are discussed as follows:</p> <ul style="list-style-type: none"> • "The focus of the prototype is entirely on data delivery. It is possible to use a similar concept for data capture. Support for situations where drawings and documents are to be updated needs to be provided" (Industry expert). • "Cross disciplinary information search must be supported. For instance, an electrician may need to have an idea of the plumbing layout. It is important for the system to support such random information needs of workers" (Construction researcher). • In the view of a construction site supervisor, because of high staff turnover, there is no great value in delivering profile-based data to individual workers. In his view, such support should only be limited at a management level, as workers keep on changing all the time on the site. 	<p>Such issues should be considered in any future application development.</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments						
	<ul style="list-style-type: none"> It was suggested by a site manager that the prototype can be used to support reporting mechanisms whereby a new person arriving for the job could know where his colleague left and start from there. An industry expert suggested, "The system may work if you have generic profiles of the on-site work-force, such as joiners, electricians, steel-fixers and HVAC engineers. However, it needs to be investigated how such a system may work at a more generic level, where such profiles are not available". Problem of viewing drawings on Pocket PC screen was highlighted by few evaluators. An illustrative comment from a construction manager was "...However, when it comes to squashing an A3 or larger drawing onto a Pocket PC screen, that is where a major challenge lies". 							
<h4>4. Tracking Sub-System</h4>								
	<p>Evaluators Feedback on the sub-system Interface:</p> <p>There was a general consensus amongst evaluators (83% agreed or strongly agreed) that the tracking sub-system interface is easy enough for an average mobile construction worker to learn and use.</p> <div style="text-align: center;"> <table border="1" style="margin: auto;"> <tr> <td>Strongly agree</td> <td>55%</td> </tr> <tr> <td>Disagree</td> <td>11%</td> </tr> <tr> <td>Agree</td> <td>28%</td> </tr> </table> </div>	Strongly agree	55%	Disagree	11%	Agree	28%	<p>Two evaluators cited the difficulty to view map-details, such as logical areas on the PDA screen.</p>
Strongly agree	55%							
Disagree	11%							
Agree	28%							
	<p>Appropriateness of using WLAN technology for On-Site Tracking: A technology expert raised the following</p>							

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	<p>concerns about using WLAN-based tracking technologies:</p> <ul style="list-style-type: none"> • WLAN-based tracking relies on signal strength measurements. However, because of the dynamic nature of the activities on the construction site (e.g. moving cranes etc.) signal strength continuously varies. This may affect the overall reliability of the tracking results. • A WLAN-based tracking system needs to be calibrated before it can be used. Because of the changing site conditions (such as changes in soil, structure, plant, site-layout, etc), it will be important to calibrate site almost on a regular basis to achieve accurate tracking results. This would make it almost impossible to manage such a system. It may be possible to use such a system to track the movements of large plants where lack of accuracy will not be a big problem. 	<p>Such concerns are valid. WLAN technology relies on calibration and signal-strength measurement. Changes in the site layout because of the on-going work will require calibration after regular intervals, which may not be possible. Thus, WLAN may not be the most appropriate technology for location tracking in the early stages of the construction project. But its use can be considered, once the structure has been erected. The key advantage of a WLAN based tracking system is that no additional infrastructure is required, provided the WLAN is already set-up.</p>
	<ul style="list-style-type: none"> • Proximity-Based Warning is Not Very Efficient: A construction manager mentioned that, "In the prototype, you have used proximity-based warning whereby anyone in a 2 metres range is warned. Rather than proximity warnings, it may be more useful to restrict entry of a person in a certain area or in a room". • Utility of Displaying Warning Messages on PDA: Three evaluators raised concerns about delivering SMS like H&S warnings on workers' mobile device, on the basis that it may be too late to display a possible warning or it may cause distraction to busy personnel. A project manager suggested that a non-PDA monitoring device with alarm may be more suitable to ensure safety and security purposes. 	<p>Such issues should be considered in any real-life application development. Ideally, a site-safety system should have both pro-active (e.g. warning site-staff of potential hazards) and reactive (e.g. alarms) features.</p>
<p>6. VoIP Sub-System</p>	<p>All of the evaluators agreed that VoIP system interface is easy enough for use by construction workers.</p>	<p>There was a total consensus that the system is</p>

No.	Evaluator's Feedback On The Prototype Implementation	Comments
	 <p>A 3D pie chart illustrating the distribution of responses. The largest slice, representing 'Strongly agree', is 65%. The next largest slice, 'Agree', is 35%. The remaining two categories, 'Disagree' and 'Strongly disagree', each represent 0% of the total responses.</p>	<p>easy to use.</p>
	<ul style="list-style-type: none"> • A technology expert suggested the VoIP should be tested under noisy site conditions, to ensure it works well under those circumstances. • A construction researcher highlighted the fact that as VoIP technology is essentially free with no call charges, there is a potential for misuse. He suggested restricting access to certain numbers may be useful. • Another technology expert highlighted the fact that in the short term, VoIP solutions may be expensive to set-up, because of the cost of hardware and those of setting up the network. It was also suggested that currently there is a lack of availability of VoIP phones and other rugged VoIP equipment in the market. • An industry expert commented that such a VoIP system will be an ideal replacement for site radios, as one device will be able to serve both voice and data needs. It was also suggested that a combination of phone and instant messaging may work well i.e. if a worker is busy, an instant message can be left. • "Voice may become a key business driver for promoting the uptake of other applications" (a project manager). 	<p>These comments/suggestions should be considered in any future application deployment.</p>

8.5.2. Evaluators' Feedback on Prototypes' Relevance to the Industry's Needs

The charts in the Figure 8-3 illustrate statistics compiled from the evaluators' responses to the question "I think there is a need for such a system in the construction industry".

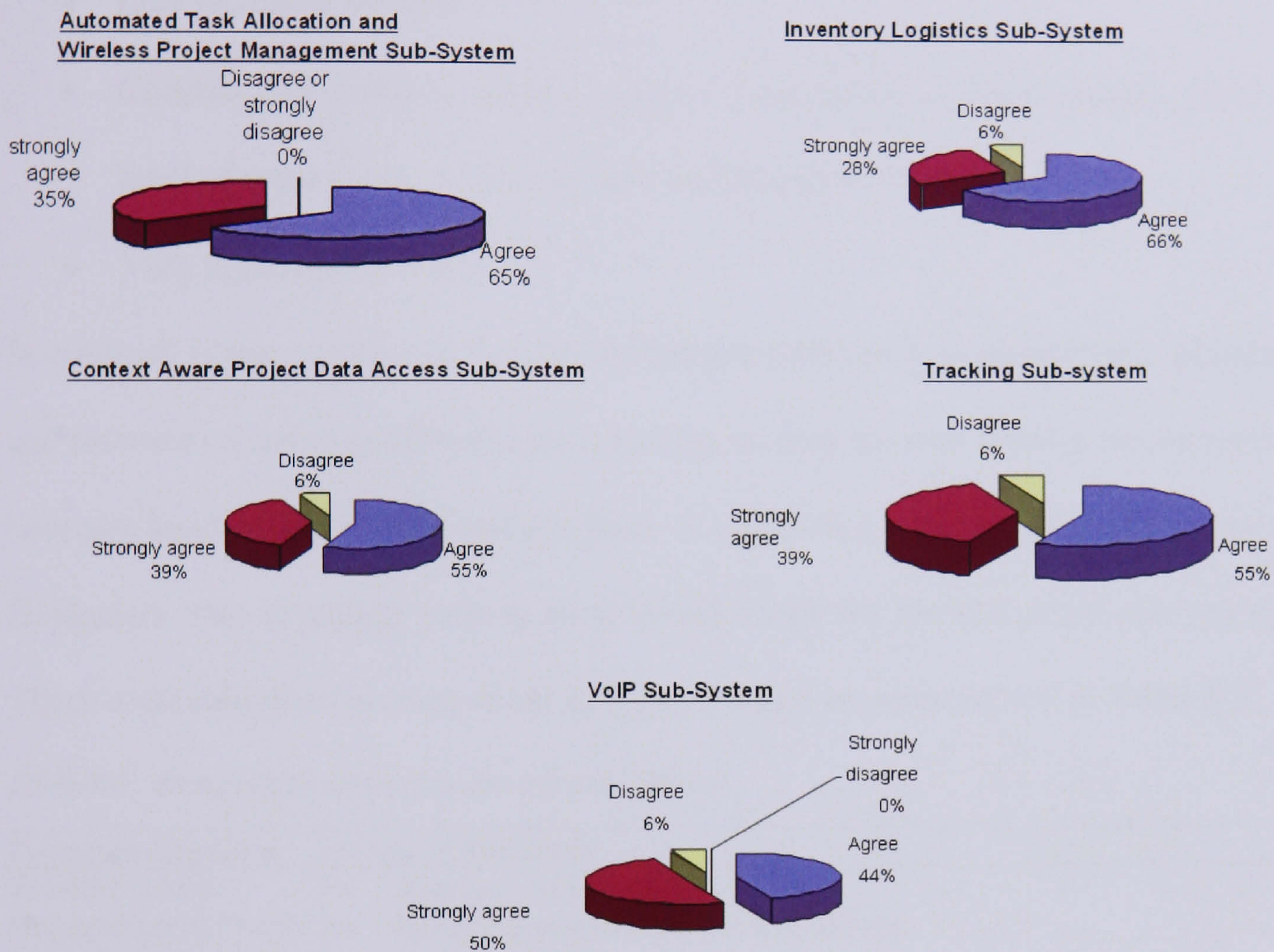


Figure 8-3: User Response to the question, "I think there is a need for such a system in the construction industry"

As can be seen from the above charts, there was a general consensus amongst evaluators that there is a definite need for such a system. With a high level of agreement, it may be inferred that the industry, in general, is recognising the need for context-specific wireless service delivery. The only exception was the tracking sub-system, where some evaluators had concerns about industry relations and privacy issues related to tracking people.

It was suggested that the system presented will be more relevant for those involved in the project management (e.g. site managers, project managers), foremen and other skilled workers (e.g. electricians and plumbers). However, the utility of such a system for site-operatives (e.g. labourers) was questioned. Various reasons cited for this included:

- Low technical literacy;
- Construction industry culture related issues (such as “they require constant level of supervision, otherwise they will not work”); and
- Very high turn-over rate.

In contrast, it was mentioned that the skilled site staff (such as electricians, plumbers and foremen) stand to gain from such a system, as they are well trained, do not require constant level of supervision and can learn to use such a system with a little training.

Evaluators also described various areas of relevance for the individual sub-systems.

These were described in more detail in Table 8-1 and are summarised in Table 8-2:

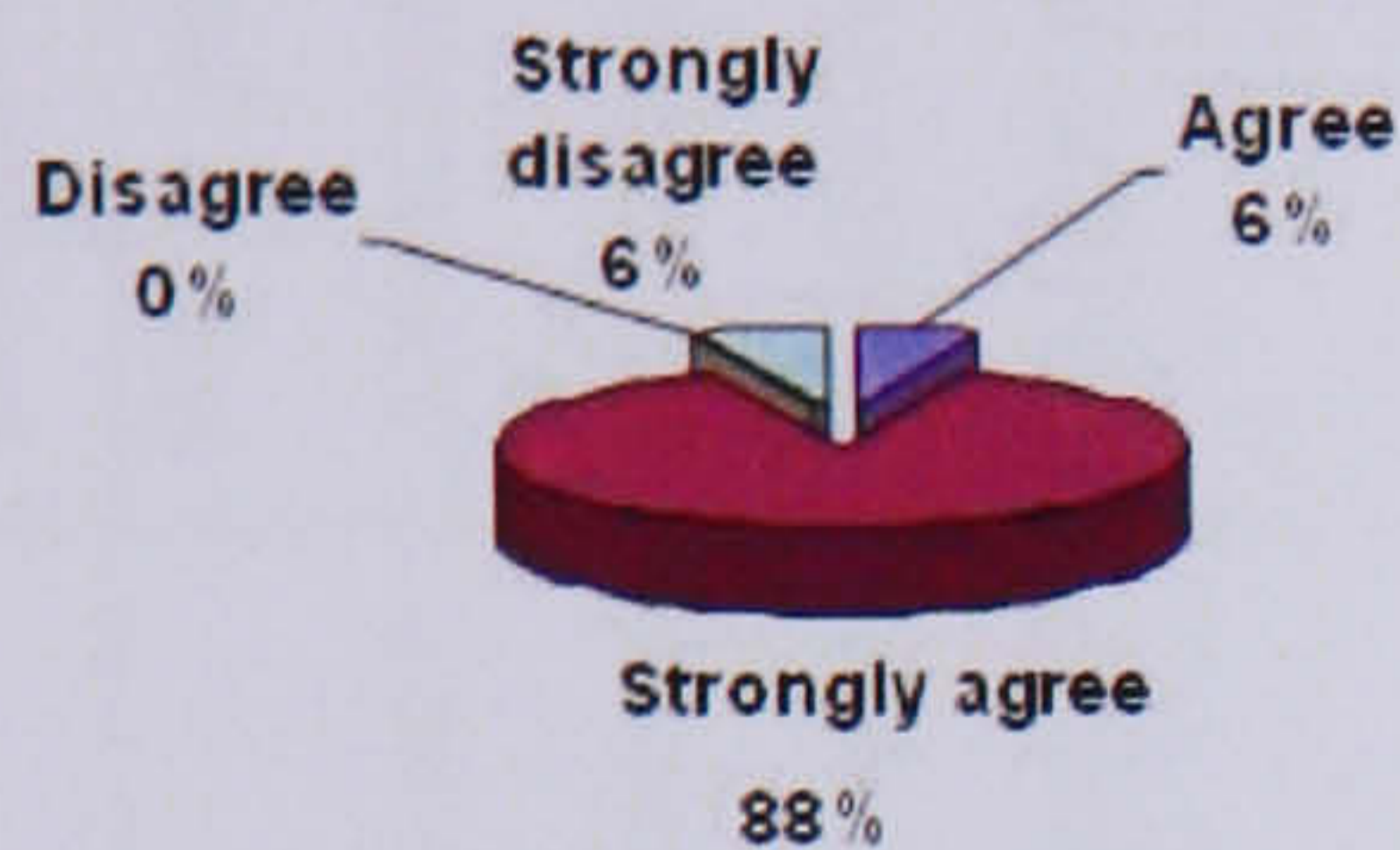
Table 8-2: Prototype’s relevance to the Industry’s Needs

Prototype Use-Case	Areas of Relevance
Wireless Project Management & Profile Based Task Allocation	<ul style="list-style-type: none"> • Real time data access • Recording details at the point of activity • Auditing task lists • Accountability
Inventory Logistics	<ul style="list-style-type: none"> • Managing inventory
Context-aware Data Access	<ul style="list-style-type: none"> • Version Control and delivery of back up information for drawings • Delivering H&S data • On-demand, relevant information delivery to workers • Accessing specific technical data. • Version control • Delivery of H&S information
Tracking	<ul style="list-style-type: none"> • Locating people on large construction sites. • Security & Payroll • Managing inventory items • Can be used for training purposes • For disaster management- can see at any time how many people are in a disaster zone and rescue them • Building Maintenance and facilities management • H&S benefits
VoIP	<ul style="list-style-type: none"> • Using one device to serve both voice and data needs

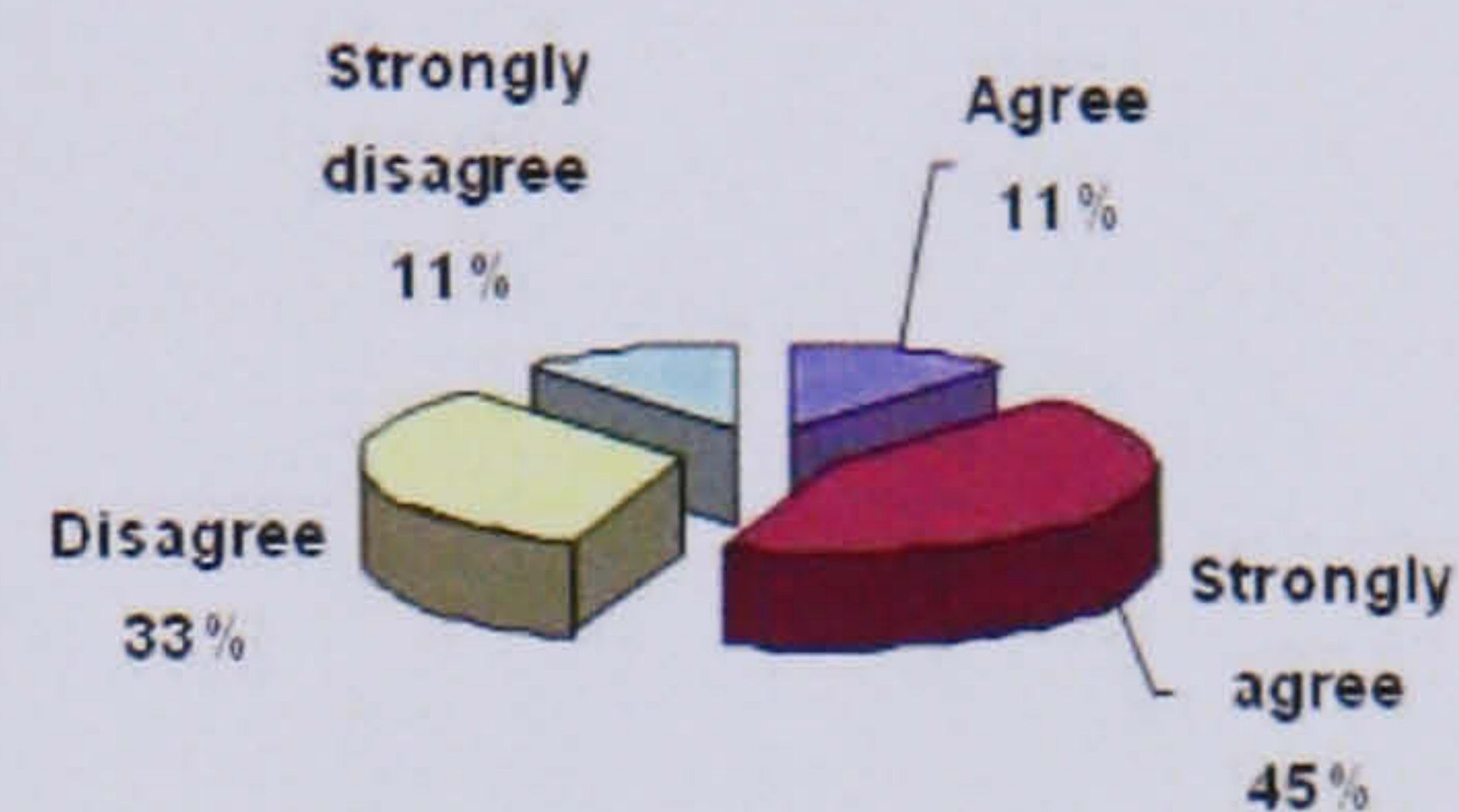
8.5.3. Evaluators' Feedback on Barriers to Implementation

The charts in Figure 8-4 illustrate statistics compiled from evaluators response to the question that “I think implementing such a system in the construction industry faces major barriers”.

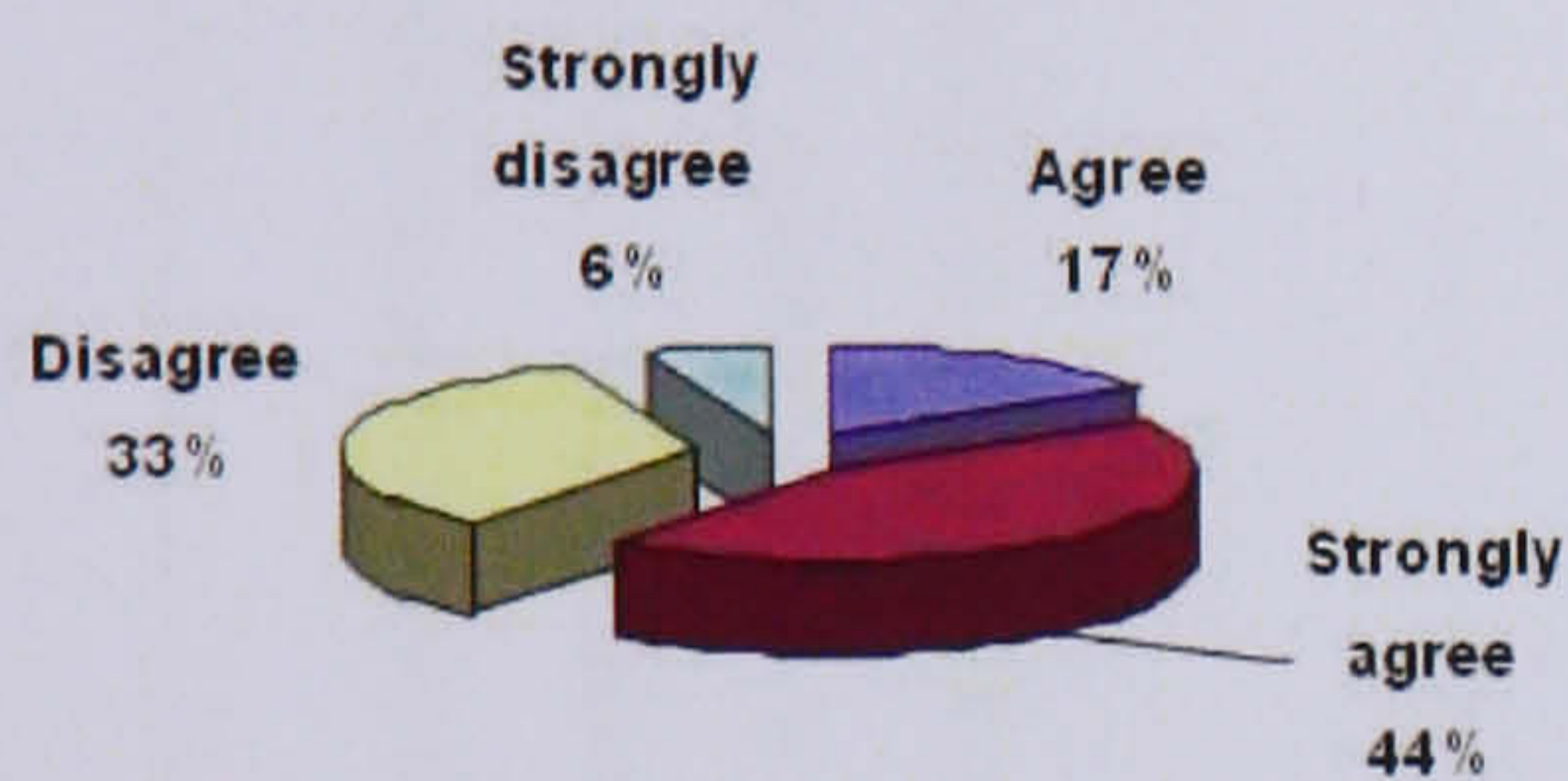
Profile Based Task Allocation and Wireless Project Management Sub-system



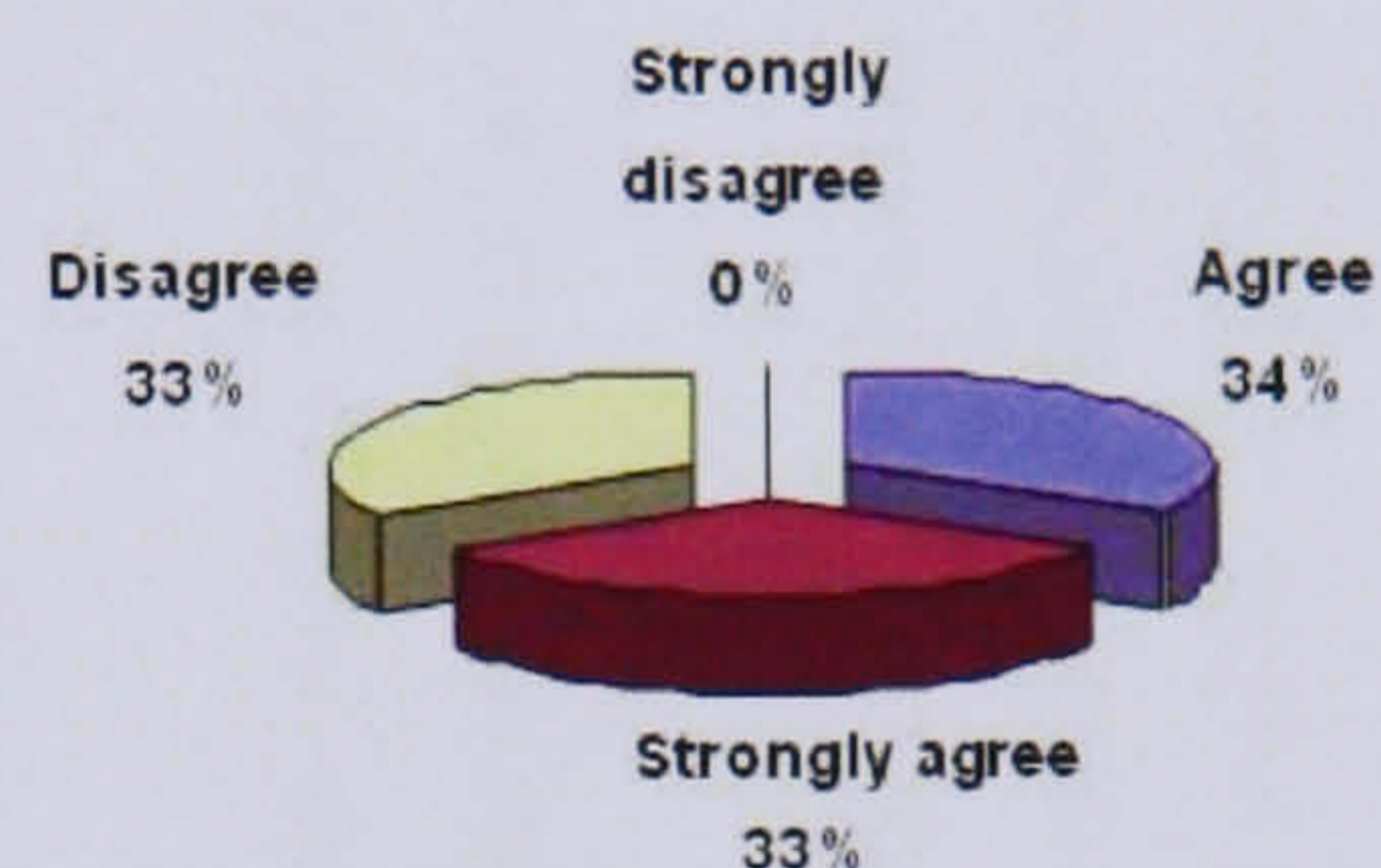
Inventory Logistics Sub-System



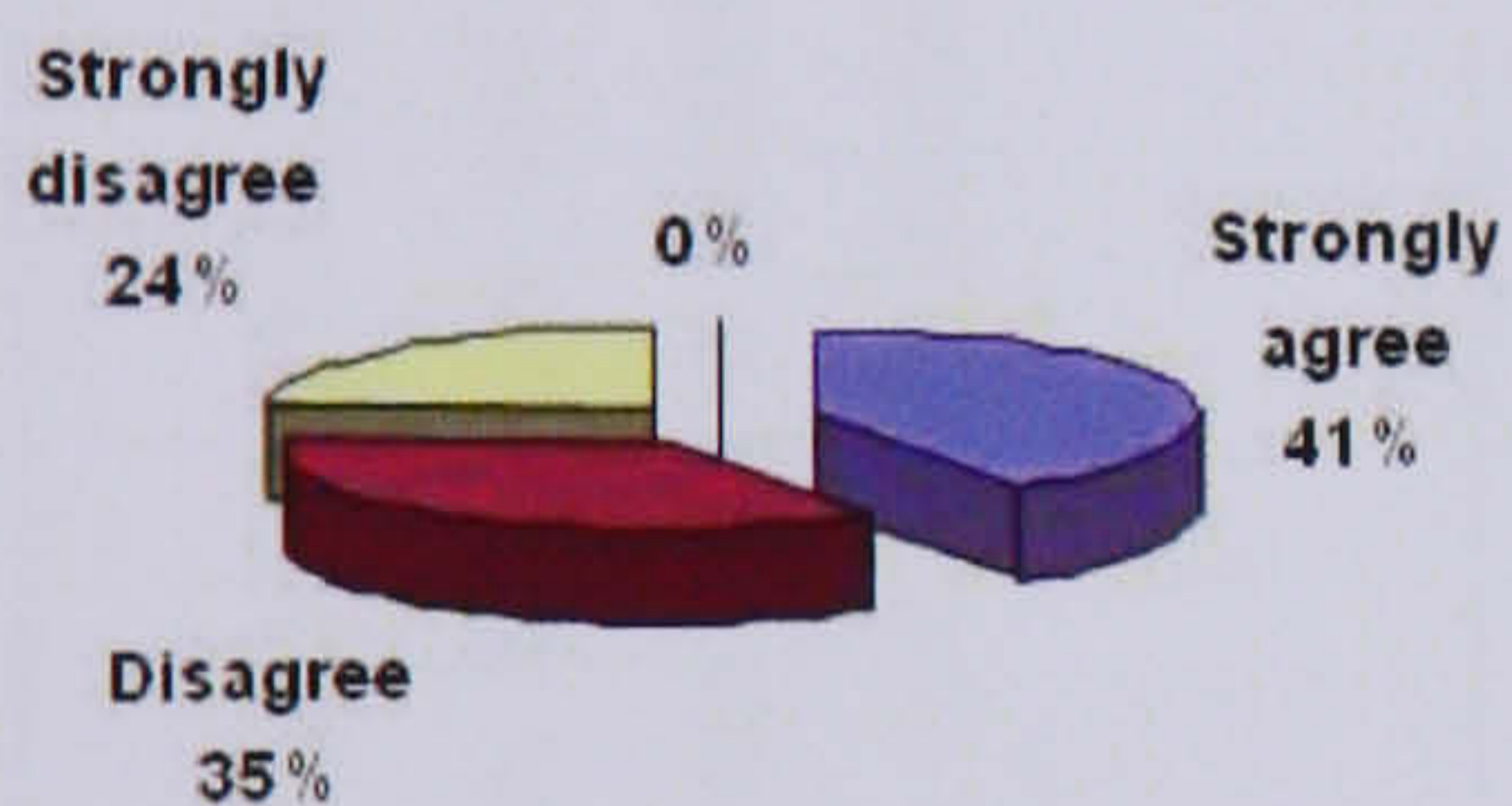
Context Aware Project Data Access Sub-System



Tracking- Sub-System



VoIP Sub-System



Overall System

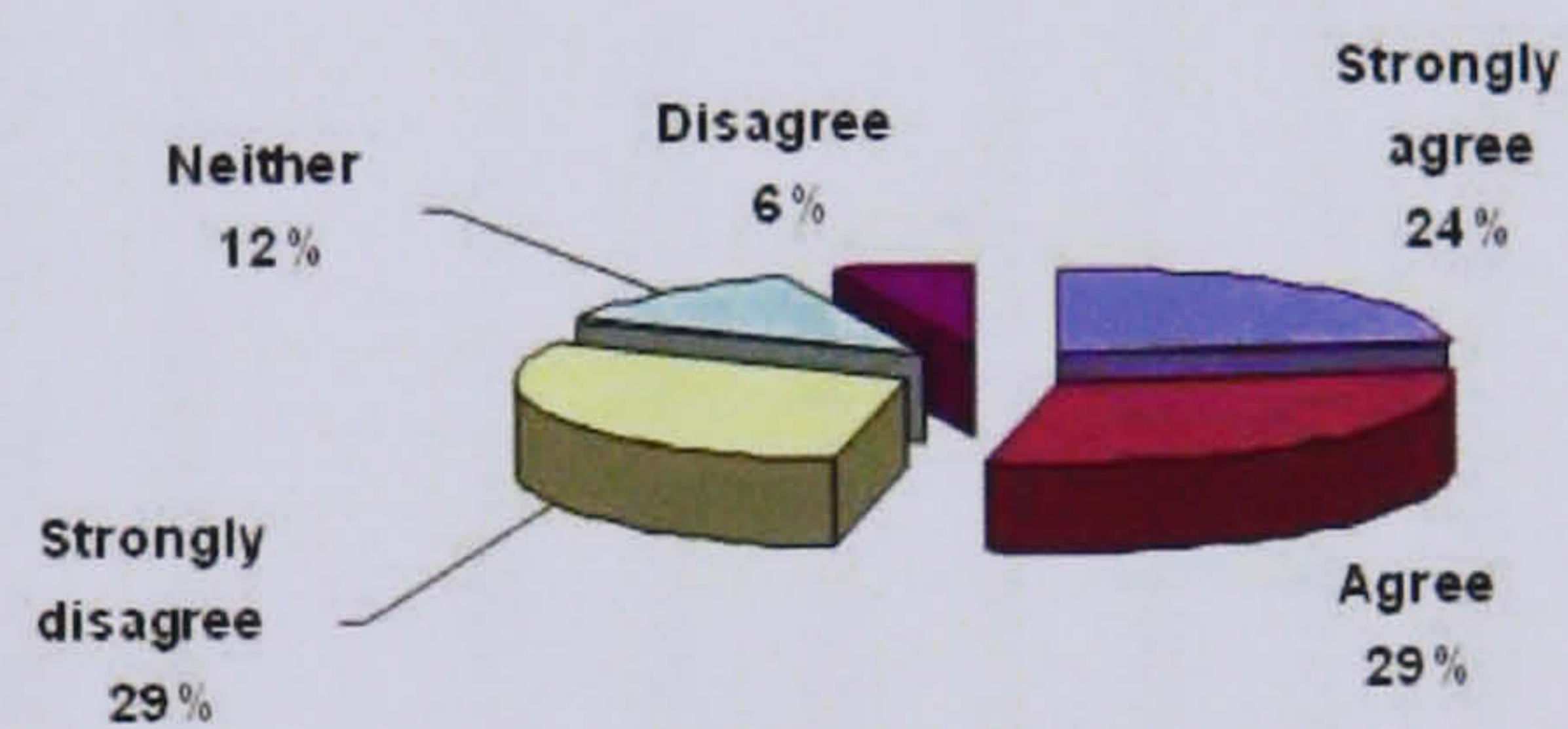


Figure 8-4: User Feedback to the question, “I think implementing such a system in the industry faces major barriers

As can be seen from the above charts, that majority of evaluators agreed or strongly agreed (i.e. Automated task allocation and wireless project management - 94%, Inventory Logistics - 56%, Context-aware Project data access - 61%, tracking - 67%, VoIP - 41%, Overall system - 53%) that implementing such a system faces major barriers in the construction industry. Identified barriers are discussed in Table 8-3:

Table 8-3: Evaluator's feedback on barriers to prototype implementation

No.	Evaluator's Feedback On Barriers To Prototype Implementation	Comments
1.	<p>Cost Barriers</p> <p>Cost barriers were identified as a major hurdle in the uptake of such a system. It was pointed out that implementing such a system would be expensive, involving costs such as software, hardware and implementation costs (e.g. consultants' costs). At the same time, additional costs will be incurred in training the workforce. A site manager suggested that one way of controlling the costs may be to provide limited access (i.e. only to the specific high end users such as project managers, and site managers) to such a system.</p>	<p>For a general uptake of such a system by the construction industry, it is important that the advantages far out-weigh the costs. However, addressing specific cost-related issues are beyond the scope of this work.</p>
2.	<p>Technology Adoption Barriers</p> <p>Various technology adoption barriers were identified during the evaluation process. These include:</p> <ul style="list-style-type: none"> • The Age Factor: An illustrative comment by a site manager was, "We have a problem with the older people, to get them to use the new technology. They are not computer literate and are slow to learn. Younger people learn computing in school. They learn technology fast". • Low Technical Literacy: An illustrative comment was "Many of the construction workers traditionally have not been highly computer literate. A large percentage comprises immigrants. Convincing and training a less literate workforce to use the latest technology is a problem" (Industry Expert) • Site Processes are Slow To Adopt New Technology: An industry expert pointed out that construction site processes are slow to adopt new technology laggard and are very often at the lower end of the technology adoption curve. It was suggested that the focus ought to be on the quicker wins for different types of trades within the industry. • Reluctance to Change: Reluctance to change was identified as another potential barrier by many evaluators. An illustrative comment by a project manager was, "Very often people and process issues prove to be big barriers to the 	<p>In recent years, many research initiatives have focused on addressing such issues. It is important to combine technology research in Construction IT with social research, to adequately address such issues.</p>

No.	Evaluator's Feedback On Barriers To Prototype Implementation	Comments
	<p>adoption of new technology. New technology invariably causes a shift in the existing business processes. As a result, the workforce requires new skills and qualifications. There are other management issues involved as well. For example, there is often resistance to the introduction of new technology or, for that matter, any other change". A project manager commented, "Some people do not want to adopt the new system. It is not simply the case of 'Your boss is saying so, so do it', rather personal preferences matter a lot".</p>	
3.	<p>Technology-related Barriers:</p> <p>Various technology-related barriers were highlighted by evaluators. These include lack of rugged hardware, lack of successful applications, poor integration with the existing systems, and complexity of a technology.</p>	<p>With the emergence of new and more robust technologies in recent years, it is hoped that many of the technology limitations will be addressed within the 10 year time-frame.</p>
4.	<p>Fragmented Nature of the Construction Industry:</p> <p>Many evaluators highlighted the fragmented nature of the construction industry as a major barrier in the uptake of such a system.</p> <ul style="list-style-type: none"> ● During the evaluation of the Inventory Logistics sub-system it was stated that getting the entire supply chain to use the tagging technologies is a big assumption. Various issues were identified in this context, including: <ul style="list-style-type: none"> ○ Who will pay for the tags and other technology costs? ○ Who will use the tagged information? ○ Who stands to gain the maximum benefit? <p>An industry expert suggested that it is important to get a national supplier or contractor buy-in to this idea to get it to work. Another evaluator suggested that such technology is more applicable to organisations with their own integrated supply chains.</p>	<p>Things have much changed since Latham (1994) and Egan (1998) report. However, still much need to be done. The construction industry gradual move towards partnering the supply-chain is one positive initiative.</p>

No.	Evaluator's Feedback On Barriers To Prototype Implementation	Comments
	<ul style="list-style-type: none"> • Industry fragmentation problems were also identified as a barrier during the evaluation of Context-aware Project Data Access Use-Case where it was identified that it may be difficult to implement a centralised information repository because of the fragmented nature of the industry. A researcher commented that the use of context-aware information delivery may be more feasible in design and build projects. • An industry expert stated that, "The construction industry is very project driven. Many players have not worked together previously. So a general contractor may hire sub-contractors they did not know before. Whoever is in control, architect or a contractor, will use his own technology. Thus, very often technologies used in different projects are different". Similar views were expressed by a project manager, who said "Very often project managers or specialist contractors are involved in several projects at once. There is, therefore, a need for consistency in the use of technologies across different projects". 	
	<p>Usability Issues</p> <p>Generally, there was a positive feedback about the usability of the prototype system. However, evaluators made a few comments about general usability issues with regards to the use of Pocket-PC like devices. Some of these comments are described below:</p> <p>Many evaluators identified different usability issues as a barrier to the uptake of mobile technologies. Some of these issues were generic in nature, and not strictly related to the prototype implementation. They included:</p> <ul style="list-style-type: none"> • Relatively small Pocket PC display screens; • Text entry using a stylus - difficult for workers with big-fingers or those wearing gloves; • Difficulty of viewing the PDA screen in the sun light or usage in the rain were also pointed out as potential barriers; • Difficulty of using PDA with one hand only; 	<p>It is critical to address the usability issues for an uptake of the new technology by the construction industry. There is a need to explore multi-modal interfaces such as speech input and output, visual touch-screens to make mobile applications easy to use for construction work force.</p>

No.	Evaluator's Feedback On Barriers To Prototype Implementation	Comments
	<p>Harsh on-site conditions were also identified as a barrier to the uptake of the Pocket PC and other mobile devices, with a sensitive touch screen. However, this view was not agreed to by everyone, as pointed out by one site manager: "When mobile phones were introduced, they said that it would not last for 5 minutes in the harsh site conditions. Today everyone on the site has one in his pocket. I think if workers on-site think it is a useful instrument, they take good care".</p>	
5.	<p>Security and Trust Issues</p> <p>Security was another persistent theme identified by many evaluators as a potential barrier to the uptake of such a system. Specific security issues identified include:</p> <ul style="list-style-type: none"> • The feasibility of storing sensitive data on mobile devices. If a mobile device is lost, the stored data on the device is lost as well; • Possibility of data access by unauthorised persons; • Possibility of someone hacking into the wireless network. <p>An industry expert commented that trust issues involved in the supply chain, such as the need for a signature, are important to be addressed in the prototype.</p>	<p>It is important to address security and trust issues, to address the concerns of many construction companies deploying wireless applications.</p>
6.	<p>Industry Relationship Issues</p> <p>During the discussion of the tracking use-case, privacy issues were identified as a major barrier by many evaluators. An illustrative comment by a site manager was "If the system is just used to track where people are and what they are doing, this may cause a lot of grievance". It was suggested that to get round the Big-Brother concerns, it will be better to focus more on the H&S issues, where there is relatively less resistance.</p>	<p>It is important to address such concerns.</p>

8.6. Discussion and Summary

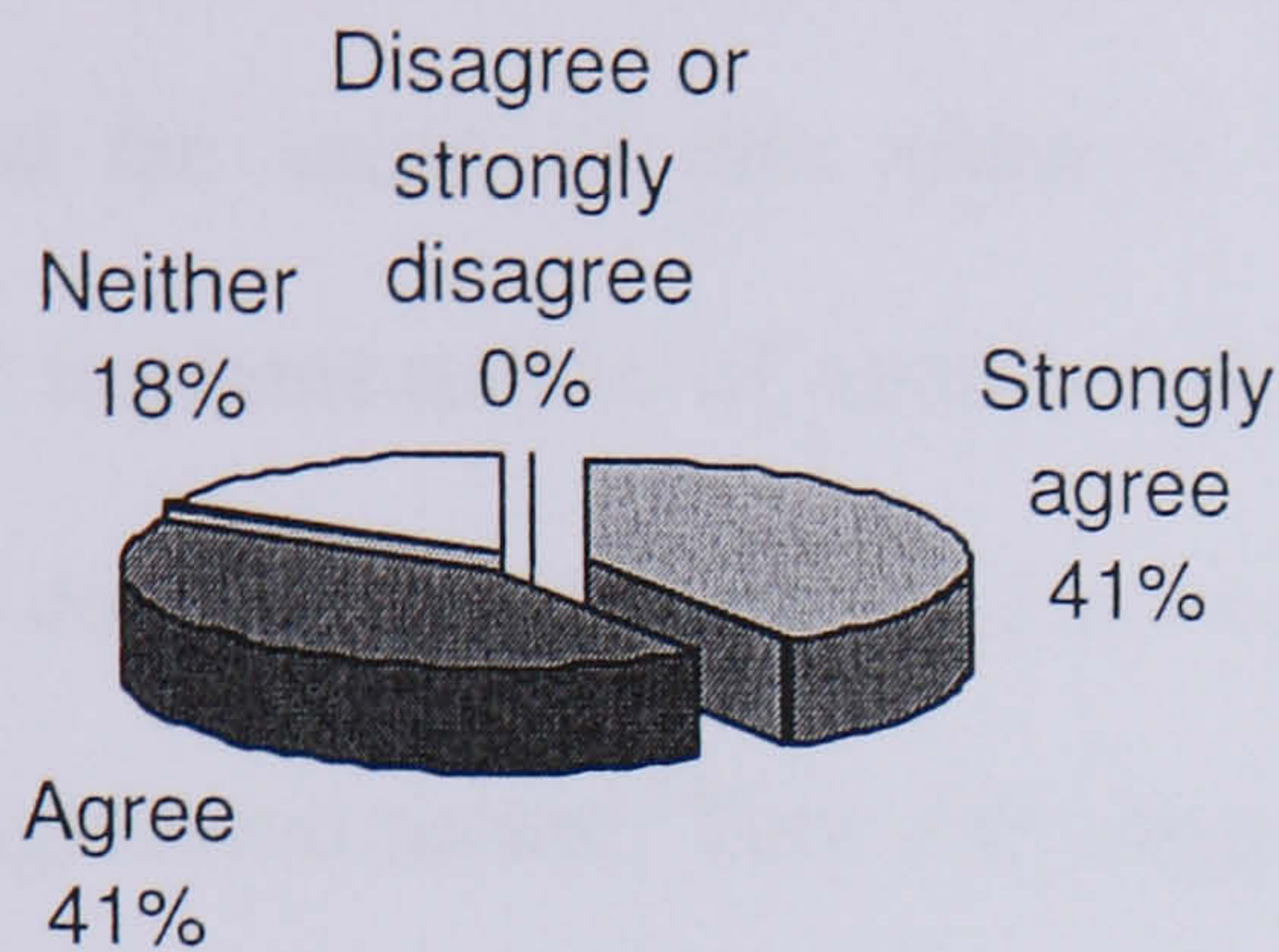
Generally, there was a positive feedback from evaluators about the prototype's relevance to the industry's needs. The evaluation process allowed them to explore possible future context-aware applications, and they took a keen interest in the presented concepts. Few illustrative comments were:

- “Prototype and research is an important step at iteratively arriving at useful mobile applications for the construction industry” (Technology Expert)
- “It will be nice to see such a system in use. I am a great believer in the use of technology” (Site manager).

The user feedback also validated the requirements that were derived from the SUNA process (Chapter 6). All of the four technology experts interviewed agreed that the prototype provides a sound basis for further technology development. Though evaluators came from quite diverse backgrounds, rather similar subjective perceptions and evaluation of the system were given about various issues including usability, functionality and security. At the end of evaluation process, the evaluators were asked questions about overall system usability. 82% of the evaluators thought that the overall system was very usable while 70% thought that construction workers will be able to learn to use the system very quickly (Fig 8-5). Evaluators came from quite diverse background, and majority of them had not used a Pocket-PC device previously. To judge the effectiveness of the evaluation process, it was important to ensure if they understood the prototype and underlying technology concepts. 80% of the respondents reported no problem in understanding the presented technology concepts, while 20% mentioned that it was difficult to understand the various use-

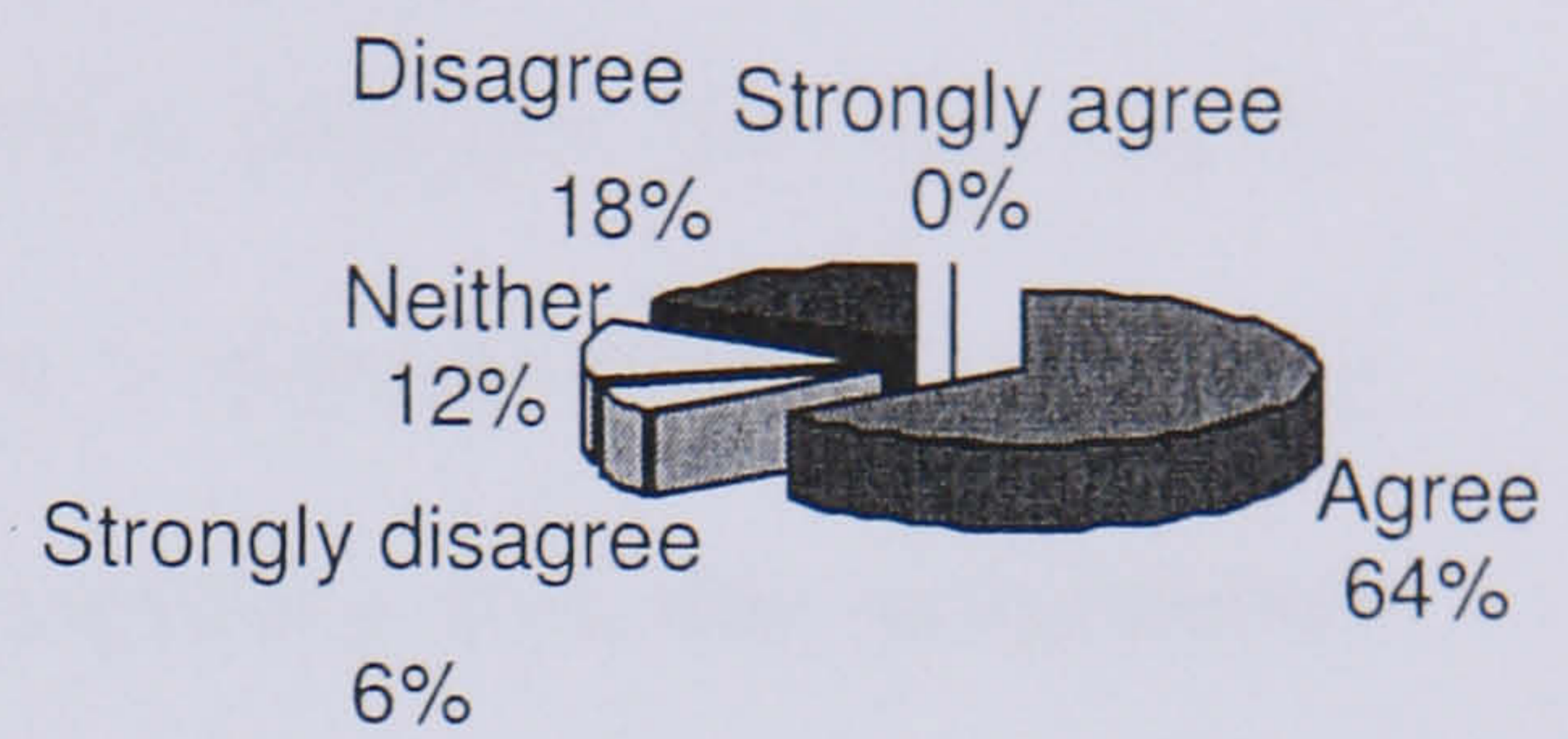
cases. However, few evaluators suggested that real evaluation of such a system will be by its application in a real life construction project.

I think overall the system is very usable



(a)

Construction workers will learn to use such a system pretty quickly



(b)

Figure 8-5: User Feedback on overall system usability

The prototype implementation also served as a technology demonstrator, to help end-users identify and discover needs that they may not have thought about otherwise (e.g. need for capturing context history etc). Also, evaluator's expressed a desire to see additional features in the prototype. However, the identified user expectations of the prototype system should be seen in the context that the prototype developed in this research is essentially a proof-of-concept application. It was developed to demonstrate the application of context-aware information delivery in realistic construction scenarios. The focus was to prove the principles rather than to cover the complete domain, as would normally be the case with commercial software.

It was also observed that different evaluators had different expectations from the prototype system. Generally, evaluators with a high level of IT literacy expected more complex functionality (such as an ability to capture context history) , whereas evaluators with basic technological literacy just wanted simple functionality (such as wireless project management or ability to track items).

Also, during the evaluation process, many barriers were identified which were presented in Table 8-3. However, most of the identified barriers (such as cost barriers, technology-adoption issues, fragmented nature of the industry, etc) (although valid) are beyond the scope of this research. These barriers highlight the fact that for successful implementation of such a technology, the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user-acceptability and its fragmented nature. This will require the industry to move beyond its existing practices. Various suggestions made by evaluators are collated into recommendations for future developments and are presented in Chapter 9. Also, the evaluators identified various technology-related barriers such as lack of available hardware, limited battery life, high deployment costs, security concerns, etc. These are valid points; however, they must be seen in a background that the concepts were presented in a 10 year time-frame. With a fast pace of technology change, it is hoped that many of these barriers will be addressed in due course. In summary, the prototype implementation satisfied the original research objective of demonstrating the context-aware information delivery concepts in realistic construction situations. However, successful deployment of such a technology in the construction industry would require addressing various construction industry and technology-related barriers.

Chapter 9: Conclusions and Recommendations

9.1. Introduction

This chapter presents a general summary of the overall research, and conclusions and recommendations. This research focused on context-aware information delivery for mobile construction workers. A scenario-planning approach was used to understand the construction industry requirements. The investigation resulted in the development of a generic architecture and an implementation and evaluation of the resulting prototype system. The research concludes that context-aware services delivery has the potential to significantly improve support for mobile construction workers. However, the industry needs to address cultural and social factors specific to the construction industry. This chapter ends by making recommendations for practical applications and future work.

9.2. General Summary

This section reviews the aims and objectives of this research and compares it with the research undertaken. The rationale of this research was based on improving existing mobile IT applications in the construction industry through better context-awareness. The research aim was to “to investigate the applicability of context-aware information delivery technologies in the construction industry”. In order to achieve this aim, the following specific objectives were defined:

1. To review developments and trends in the use of context-aware computing and enabling technologies such as the Semantic Web, Web Services, (multi) agent and wireless communication technologies;
2. To develop a conceptual framework and futuristic deployment scenarios of context-aware information delivery for mobile construction workers;
3. To develop an understanding of the construction industry's requirements for context-aware information and services delivery;
4. To implement a prototype application based on the construction industry's requirements that demonstrates various aspects of context-aware information delivery in realistic construction situations; and
5. To evaluate the prototype with the end-users and the construction industry experts.

The specific tasks undertaken in this research, with respect to research objectives are summarised below.

Objective 1: To review developments and trends in the use of Context-Aware Computing and Enabling Technologies

The state-of-the-art review of Mobile IT applications in the construction industry (as presented in Chapter 1) revealed that the importance of using Mobile IT tools to support the information needs of mobile construction workers has long been understood. The literature review also showed that it is a conclusively established fact amongst construction researchers that Mobile IT applications can play a critical role in improving construction productivity and efficiency. However, various researchers differ in the way these tools should be implemented and used. The state-of-the-art

review also highlighted the key limitations of the existing approaches, which included:

- From a methodological viewpoint, existing mobile IT deployments in the construction industry see support for mobile workers as a "simple" delivery of the static information. They are unable to take into account the changing context of the mobile worker and the dynamic project conditions. This often results in a mismatch between the technology and the user needs;
- From a technical viewpoint, existing Mobile IT applications lack semantic awareness which is a major hurdle in developing intelligent systems capable of matching the user-context (and resulting information needs) to available documents and resources;
- From a system integration viewpoint, existing Mobile IT applications are poorly integrated with the existing desktop-based infrastructure, resulting in a creation of another island in "Construction Islands of Automation" (as illustrated by Hannaus (1998));
- From a user-perspective, often technology-centric Mobile-IT applications have failed to meet the information needs of mobile construction workers;
- From a technology integration perspective, there has been limited work to integrate emerging technologies (such as the Semantic Web, Web Services, Intelligent Agents and Context-Aware Computing) within the construction work environment.

On the basis of the aforementioned limitations, it was asserted that future mobile IT applications should be aware of the worker's context, in order to ensure that the right information is delivered to the right person at the right time. Awareness of semantics

would facilitate such information delivery, by matching (semantically-aware) available resources to the captured context. Also, the use of open-standards resource discovery and integration standards (such as Web Services) will ensure an ability to dynamically discover and integrate with both inter and intra-enterprise resources based on the captured context. Critical to the deployment of future Mobile IT applications is the understanding of the end-user needs. Also, there is a need to integrate various emerging technologies in the work environment, to provide optimal support for mobile construction workers. Chapter 3 defined the concept of context-aware information delivery and reviewed related work in this area. It also elaborated on technology concepts related to context-aware computing such as location-based services, user profiling, ubiquitous computing and wireless sensor networking.

Objective 2: To Develop a Conceptual Framework and futuristic deployment scenarios of context-aware information delivery for mobile construction workers

This research reviewed various context-aware information delivery frameworks and presented the WiSeCon framework (Section 3.5.2), which aims to create a pervasive, user-centred mobile work environment with an ability to provide highly specific data and services to mobile construction workers on an as-needed basis. The framework is based on multiple tiers, which include context-capture, access, middleware, context-inference, context-integration and contents and applications tier. Various enabling technologies related to the WiSeCon framework were reviewed and it was explained (in Chapter 4) that how, by exploiting the convergence and synergy between different enabling technologies, it has become possible to deliver intelligent wireless support for mobile construction workers. Based on the WiSeCon framework, Chapter 5 presented futuristic deployment scenarios illustrating the use of context-aware

technologies in realistic construction scenarios including supply chain automation, project document management, third party services provisioning, construction task automation and intelligent construction site. Each scenario was set in a 10 year time-frame and was analysed, by bringing together the perspective of 13 experts from different backgrounds.

Objective 3: To develop an understanding of the construction industry's requirements for context-aware information and services delivery

A scenario-based user needs analysis (Helvert et al, 2003) approach was employed to develop an understanding of the construction industry's requirements for context-aware information and services delivery. Semi-structured interviews were held with the industry experts. During the interviews the scenarios were used purely as challenges, without regard or emphasis on one scenario being more or less probable than another. The key objective of the analysis was to pose the question of next generation context-aware mobile applications in the construction industry and to identify the industry's needs and application areas with the maximum potential.

Objective 4: To implement a prototype application based on the construction industry's requirements that demonstrates various aspects of context-aware information delivery

Based on the Construction industry needs identified during the interviews, design goals were identified and the system architecture was subsequently based on these design goals. The conceptual modelling was depicted in UML with a use-case driven approach, to illustrate the functional requirements of the system. Various system design choices were discussed and a physical architecture was presented. The

prototype implementation provided an initial working model of a large, more complex system. The prototype was implemented on a Pocket-PC platform and a component-based approach towards system development was adopted.

Objective 5: To evaluate the prototype with the end-users and the construction industry experts

The prototype was evaluated with relevant end-users. During the evaluation process, a combination of qualitative and quantitative methods were used, in addition to the high number of users tested (n=23), which provided a reliable evaluation of the prototype system. A number of results at different levels of detail were obtained. Generally, there was a positive feedback from evaluators about the prototype implementation and relevance to the industry's needs. The evaluation process also provided a positive validation of the concept of context-aware information delivery for mobile construction workers. It allowed evaluators to explore possible future context-aware applications, and they took a keen interest in the presented concepts.

9.3. Conclusions

This research project investigated the applicability of context-aware information delivery technologies in the construction industry. The following conclusions can be drawn from the research:

- The realisation of the vision of CAID for mobile construction workers has become possible because of emerging technologies such as ongoing miniaturisation, developments in sensor networking, the increase of computational power and the fact that broadband is becoming technically and financially feasible;

- CAID opens up new possibilities for leveraging the capabilities of mobile computing in the construction industry by using context as a filtering mechanism to deliver information relevant to the task at hand;
- Context-aware computing technologies can be used for a wide range of applications in the construction industry including improved site-logistics, object identification, real-time tracking etc) thereby enabling the creation of an intelligent mobile work environment;
- The WiSeCon framework presented a generic platform which demonstrates the use context awareness as an integral component of Mobile IT infrastructure, by addressing the key issues of context capture, context-interpretation (using Semantic Awareness), automating the use of context information (using Agent-based technologies) and discovery and integration of resources based on the captured context (using Web Services standards).
- The prototype application demonstrated that how the technology can be used to deliver a range of value-added services for construction workers based on the task at hand;
- The feedback gathered during the scenario validation and the evaluation process demonstrated that there is a keen interest in the industry in the application of the context-aware technologies and in various enabling technologies such as location-tracking, RFID and ubiquitous computing.
- Review of various enabling technologies for context-aware information delivery (i.e. Wireless communication, Web Services, the Semantic Web, Agent technologies) established that these technologies open up new possibilities for leveraging the capabilities of mobile computing in the construction, where the Semantic Web supports contextual meaning enabling

matching of captured context and available resources, Web services technologies allow dynamic discovery and integration of resources based on the captured context, agent-based technologies allows for better integration of diverse resource helping user to efficiently accomplish elements of a project plan and wireless communication technologies provide a vital communication link. Collectively these technologies have the potential to cause a paradigm shift in construction management practices by allowing mobile workers access to a wide range of data and services on an as-needed basis

- Security, usability, privacy and cost of implementation were main concerns in implementation of a CAID system;
- Results from the evaluation showed that these technologies work at the early prototype stage. However, further effectiveness of these technologies relies on the development of shared ontologies and semantic standards to ensure a uniform method of context capture, context-reasoning and context-integration;

9.4. Contribution to Knowledge

This research contributed to knowledge in three key areas (Figure 9-1). First of all, it presented a holistic view of context-aware information delivery for on-site construction operations, by presenting a conceptual framework to address key issues related to context-capture, context-reasoning and discovery and integration of resources based on the captured context. Secondly, deployment scenarios and a prototype application were developed, which demonstrated the application of context-aware computing concepts in realistic construction situations. Thirdly, this research analysed the construction-industry requirements for future context-aware information

delivery services. The contribution to knowledge by this research is explained in more detail as below:

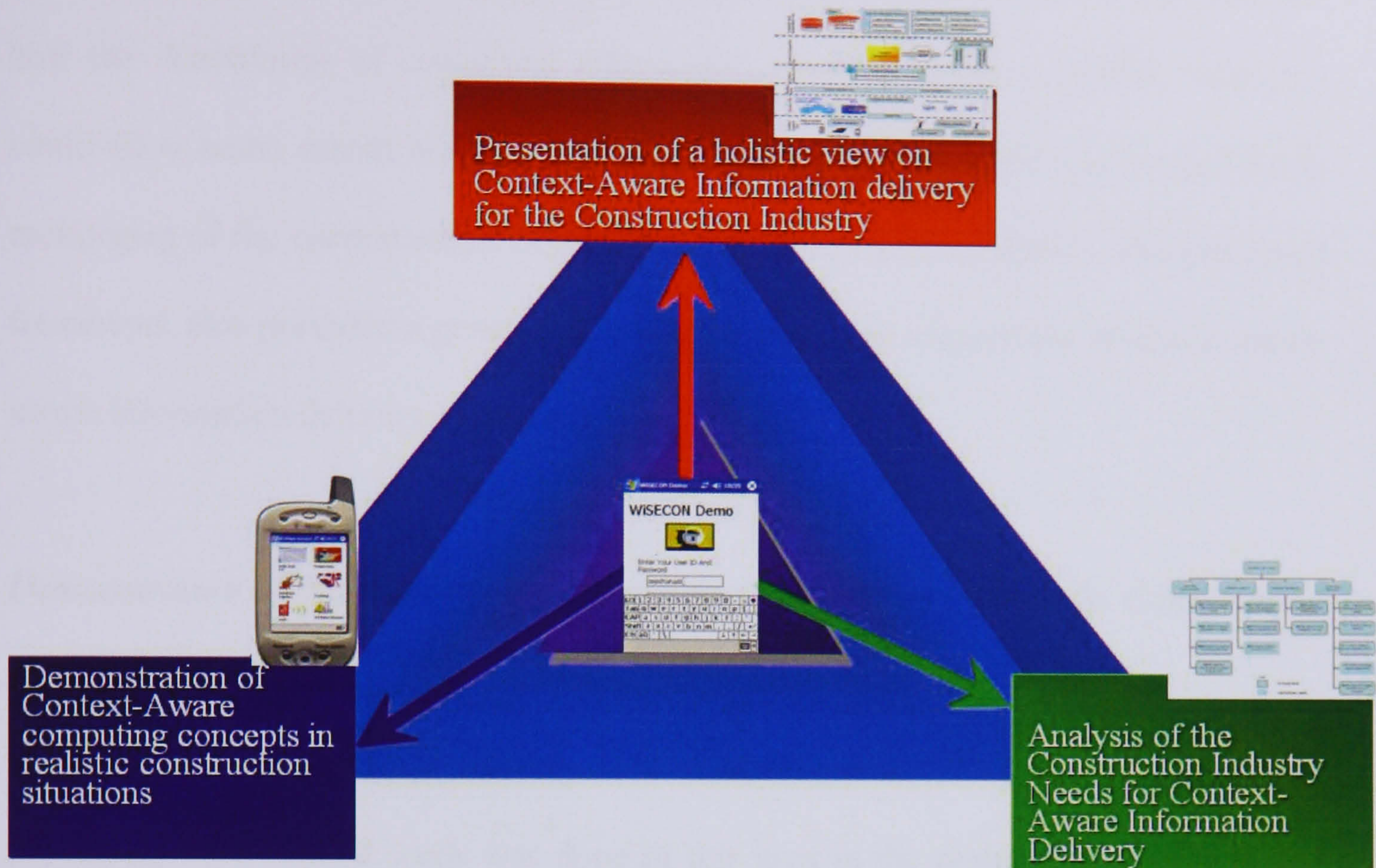


Figure 9-1: Research Contributions to Knowledge

Presentation of a holistic view on Context-Aware Information delivery for the Construction Industry

This research has demonstrated the use of context-awareness as an integral component of Mobile IT infrastructure. A holistic approach was taken to create an intelligent work environment for mobile construction workers. The focus was not merely on capturing context knowledge. Rather, the presented framework (Section 3.5.2) addressed the key issues of context-interpretation (using Semantic Awareness), automated use of context information (using Agent-Based technologies) and discovery and integration of resources (using Web Services standards) based on the interpreted context. Although many researchers have previously addressed the issue of application of these technologies individually in the construction sector, application of

these technologies in the mobile computing realm in Construction IT has not been comprehensively addressed previously. The prototype implementation demonstrated how the knowledge of contextual information (such as location, profile, task etc.) could allow better match between available resources and captured context and better monitoring of the current status of a project (e.g. the tasks completed). The presented framework also provided a generic platform which can be adapted for several context-aware information delivery scenarios.

Demonstration of Context-Aware Computing Concepts in Realistic Construction Situations

Context-aware information delivery is a relatively new interaction paradigm and previously very limited work was done in this area in the realm of Construction IT research. A substantial proportion of construction applications still rely on static modes of information delivery. The research work done in this area is primarily at a theoretical level (e.g. Rebolj et al, 2005). This research presented deployment scenarios and developed a prototype application that illustrates the use of Context-Aware information delivery technologies in realistic construction scenarios. The prototype application demonstrated how the technology can be used to deliver a range of value-added services for construction workers by intelligent interpretation of the user-context. From this perspective, this research contributes significantly to Mobile IT research in the construction industry.

Analysis of Construction Industry Needs for Context-Aware Information Delivery

The third contribution of this research is in the analysis of user needs for next generation context-aware technologies. This research used a scenario-based approach

to identify various drivers and inhibitors of context-aware information delivery services in the construction industry. During the course of this research, 36 construction industry and technology professionals participated (during the scenario validation and evaluation phase) to develop a shared understanding of context-aware information delivery needs for the construction industry. During the initial phase of this research face-to-face semi-structured interviews were undertaken with the construction industry experts. These interviews ensured a rigorous critique of the scenarios and provided a highly valued source of knowledge and perspectives to identify the industry needs and various inhibitors and drivers for each scenario in the AEC/FM. It is from the analysis of the expert validation, that a common set of user needs was established. These needs were subsequently translated into the system design goals, which acted as a key input to the design and evaluation of the prototype system. Also, during the evaluation phase prototype application helped the evaluators see a practical application of context-aware computing in a realistic situation and discover issues that they might not have thought about otherwise. This way this research played a key role in developing an understanding of the needs of the construction industry for context-aware information delivery.

9.4. Limitations

The key limitations of this work are highlighted in this section.

- A key focus of this research was to show how user context can be captured and used for information delivery to mobile workers. A prototype system was implemented and tested in a laboratory environment. Only laboratory-scale testing of the prototype system was possible as the technology was considered too novel for testing on a real life project. However, it is recognised that any

real-life implementation of such concepts may face a long list of technical and organisational challenges. This gives rise to the need for industry case-studies of context-aware computing deployments in real life projects.

- Evaluators (particularly those working in the construction industry) were enthusiastic about the concept of context-aware services delivery. Their interest was reflected in their desire to see additional features in the prototype. However, the identified user expectations of the prototype system should be seen against the background that the prototype developed in this research is essentially a proof-of-concept application. It was developed to demonstrate the principles rather than to cover the complete domain, as would normally be the case with commercial software applications.
- The prototype system focused on using 5 key context-dimensions (i.e. User identification, location, task, device type and time). However, there are many other context dimensions that can be used to support construction workers (such as existing project conditions, existing conditions on the site, weather, level of user-concentration etc). The combination of all these context dimensions in a way that actually enhances a mobile worker's experience is still a complex issue and not addressed in much detail in this work.

9.5. Recommendations

This research has revealed a number of areas for further R&D and for further improvement in the existing construction industry practices. These recommendations are discussed with respect to:

- Recommendations for further R&D
- Refinement of the prototype System
- Recommendations for the Construction Industry

9.5.1. Recommendations for Further R&D

The key recommendations for further R&D are as follows:

Need to Further Investigate Context-Aware Information Delivery in other AEC/FM Sectors

Despite the fact that the primary application domain of this research effort is on construction-site operations, many of the research findings can equally be applied in other AEC/FM sectors. It is important to investigate how different AEC/FM sectors can best utilise context-specific information and services.

Need to Address Security and Trust Issues in the System Design

Privacy of mobile workers and other security (such as integrity of information) and trust issues (such as access permissions) were highlighted by many evaluators during the scenario validation and evaluation phase of this research. These issues must be borne in mind at all stages of the design of future context-aware applications.

9.5.2. Refinement of the Prototype System

The following recommendations are made with respect to the refinement of the prototype system.

Further Need to Address Ergonomics Issues

During the prototype evaluation process, evaluators identified various limitations of Pocket-PC type mobile devices such as limited screen size, screen visibility, short

battery-life and input method. These limitations can adversely impact the uptake of mobile computing in the Construction Industry. Thus, future research should also address the hardware related issues of mobile devices that constitute barriers to their implementation on construction projects. This should include exploration of various multi-modal interfaces to address the shortcomings related to manual data entry.

Need for Further Research in Technical Issues Related to Real-Time Tracking

Location is the key factor in context-aware information delivery frameworks. Various questions related to real-time location tracking in an on-site environment were identified during the prototype implementation phase. These include:

- Is it possible to define generic logical areas for a construction site (such as site-storage, site-operations, ground Floor etc) or will it vary from site-to-site?.
- What will comprise a user's logical area?
- How is the information requirement or context of a worker in the site office different from another operating on the construction site?
- What will happen in case of overlap of wireless zones i.e. if a user is in a range of two wireless networks, how will the system differentiate his/her exact location context.
- What level of granularity may be important for on-site operations.

It is important to address such issues for effective deployment of any future context-aware systems.

Need to Integrate Context-Awareness in Construction Applications

The context-aware prototype that was developed as part of this work has demonstrated that context-awareness can effectively be used to support construction

operations. However, it is clear that there is a lot more that can be done to improve the prototype. For instance:

- Different types of sensors can possibly be used to capture a wide range of context parameters from the construction site;
- The captured context information can be integrated with meta-data, to allow better interpretation of the captured context and to provide highly specific data to users on an as-needed basis;
- Construction applications can be developed that can capture the contextual information to provide dynamic support to mobile workers, which reflect their changing context.

Need for inter-disciplinary research

Successful deployment of context-aware information delivery technologies in the construction industry would require expert input from many disciplines, including:

- Usability/Ergonomics Experts: to ensure that end-user perspective is taken in system design and implementation;
- Technology Experts: To ensure that new technology is deployed in an optimal manner;
- Social Scientists: To address user-acceptability issues;
- Construction Industry Experts: to bring in their knowledge of existing application deployments in the construction industry, and to identify application scenarios that can provide appropriate test-beds for the enabling technologies, etc.

Thus, it is important to combine usability studies, social research with the technology research to ensure that future context-aware system deployment is matched to the requirements of mobile construction workers.

9.5.3. Recommendations for the Construction Industry

Recommendations for the Construction Industry include:

Need to Undertake Industrial Case Studies

The prototype demonstrated an implementation of the context-aware information delivery technologies in realistic construction situations. However, taking into account the fact that for most construction organisations, even the use of Mobile IT is relatively new it was felt that there is a need for well-documented industrial pilot projects on real-life construction environment (or under a simulated environment in case if the technological infrastructure is not readily available). This will further demonstrate the suitability and scalability of these technologies for the construction industry while increasing the industry awareness of the potential benefits. Such projects can also be used for undertaking more detailed user studies.

Fragmentation-Related Problems in The Construction Industry Should be Addressed

The feedback gathered during the scenario validation and prototype evaluation phase of this research also identified various barriers related to the industry fragmentation which can hinder the uptake of mobile computing in construction. For widespread adoption of this innovative technology in the construction industry, it is important to address such issues.

Need for Evolving Industry Standards

The prototype implementation successfully demonstrated that these technologies work at the early prototype stage. However, a wider application of the WiSeCon framework in the construction industry would rely on the development of shared ontologies and semantic standards to ensure increased interoperability across devices, platforms and application. Since it is important that applications exchange context information, another requirement is that formats and protocols are properly designed in order to ensure this high-level interoperability. At present, construction enterprises perform their tasks in different ways, using different terminologies and modes of operation to perform day-to-day tasks. If different construction firms come up with their own ontologies (for context interpretation or for describing data), the resulting mapping and matching will be almost intractable. Various other issues highlighted in the thesis (such as the need for standard ontologies to interpret the captured context, the need for having uniform standards to discover and integrate different services, etc) also highlight the fact that the construction industry as a whole needs to evolve standards so that it can overcome technology limitations. Industry standards will also encourage wider adoption of the technology, and economies of scale may play a key role in bringing down the technology costs.

Table 9-1: Context-Aware Information Delivery - Future Road-Mapping

Issues	Description	Short-Term (0-5 Years)	Medium-Term (5-10 Years)	Long-Term (10-15 Years)
Usability Issues	<p>A wide range of usability issues related to Mobile IT applications in the construction industry were highlighted in this work. These issues included difficulty in data input, limited interface of PDAs, difficulty in using such devices in out-door environments.</p>	<ul style="list-style-type: none"> Develop easy to use interfaces (such as the icons based approach used in the prototype development) Use easy data input mechanisms, such as thumb-based keyboards, e-ink Use videos, photos and voice input and output Consider application of Multi-modal interfaces Look for new ways to integrate mobile computing technologies with n-d modelling. Use Context-Awareness to make technologies easier to use for construction workers (e.g. by better user profiling, by better understanding of user preferences, etc) 	<ul style="list-style-type: none"> Apply multi-modal interfaces, such as voice input/output, cognitive mapping. Virtual key-boards, E-Ink Increased personalisation to enable mobile devices to recognise user identity, words and commands. 	<p>Consider further improving the usability issues using various emerging technologies</p>
Trust Issues	<p>Two major issues were highlighted in this respect. These included privacy issues (The concern that technology may be used to invade user privacy) and technology mis-use concerns (issues such as access permissions, foremen recording the work to be completed whereas it is not)</p>	<ul style="list-style-type: none"> In the technology application, issues such as right access permissions for the users must be addressed; Technology should be fool-proof so that end-users can not cheat the system (e.g. recording the work to be completed when it is not) 	<ul style="list-style-type: none"> Consider improving the business processes using emerging technologies; A multi-disciplinary approach need to be adopted to address issues of trust in information delivery. It is important to involve professionals from different disciplines including human computer interaction, information technology, law, government and construction industry practitioners. Draw a fool proof system to redress the problems if things go wrong. 	<p>Use new and upcoming technologies to further improve the system:</p>

Issues	Description	Short-Term (0-5 Years)	Medium-Term (5-10 Years)	Long-Term (10-15 Years)
Real-Time Connectivity Issues	Need to provide real-time connectivity	<ul style="list-style-type: none"> Use off-the-shelf technologies (e.g. WiFi, 3G, Bluetooth) 	<ul style="list-style-type: none"> Provide seamless roaming facilities for mobile workers 	<ul style="list-style-type: none"> Use high-bandwidth technologies (such as WiMAX, ultra wide band) to enable new application scenarios
Organisational/Cultural Issues	Many organisational/cultural issues were identified during the course of this research including technology creating additional workload for users (e.g. a site-supervisor will have to take time to assign tasks to users) and industry high turn-over rate (making it difficult to introduce new technology).	<ul style="list-style-type: none"> Make technology work for users- not against them. Let workers see advantages of the technology Need to involve other disciplines such as study of human behaviour along with application of technology. 	<ul style="list-style-type: none"> Study the impact of new technology for quality of life. Adopt a multi-disciplinary approach in technology application, taking into account organisational/cultural issues 	<ul style="list-style-type: none"> Consider organisational/cultural issues in the application of new technology.
Security Issues	Various identified issues included off-line data storage, security of corporate data, possibility of external users hacking into a wireless network etc.	<ul style="list-style-type: none"> Biometrics, Voice Recognition to secure off-line data. Use IP-based wireless technologies such as WiFi, 3G which support better security features. 	<ul style="list-style-type: none"> Use wireless broad-band technologies (e.g. WiMAX, WiFi with improved range) to minimise the need for off-line data storage. Use biometric devices using unique physical identifiers such as voice, finger prints, retinal images to identify the user. 	<ul style="list-style-type: none"> Consider further improving security based on the emerging/enabling technologies
Tagging Technologies	Tagging technologies can play a key role in developing an intelligent construction site as illustrated previously in Section 5.3.5	<ul style="list-style-type: none"> Consider using off-the-shelf solutions such as RFID tags/barcodes Address process related issues such as which objects to tag, how to tag. 	<ul style="list-style-type: none"> Use intelligent tags, with an ability for sensor networking Consider using tagging technologies for a wider set of applications such as materials management. 	<ul style="list-style-type: none"> Creation of an intelligent work environment, where all the objects and machinery have an identity and establish links with other objects to take intelligent decisions. Use tagging technologies in all phases of project life cycle.
Context-Modelling & Context-Capture	A well designed context-modelling and retrieval approach is essential to appropriate implementation of a context-aware system in the construction industry.	<ul style="list-style-type: none"> Model on-site mobile worker's activities to better understand how technology can be used to serve user-needs. Consider using the Semantic Web technologies to ensure structured and 	<ul style="list-style-type: none"> Using emerging technologies such as sensor networks, include more context parameters in the context-aware information delivery paradigm. Integrate captured context with context 	<ul style="list-style-type: none"> Look for how emerging technologies can be used to capture contextual information which can be used to accelerate and optimise the process of collaboration in a dynamic project environment.

Issues	Description	Short-Term (0-5 Years)	Medium-Term (5-10 Years)	Long-Term (10-15 Years)
		<p>semantically aware description of context elements.</p> <ul style="list-style-type: none"> • Deliver data to users based on context-dimensions that are easy to capture using the existing technologies (such as location, time). • Do initial research on capturing context history (as part of the organisational knowledge data-base) • Address traditional dimensions are context such as location, time, profile. 	<p>history as part of organisations larger knowledge management efforts (e.g. What happened in the past in a particular situation and what actions should be taken in the existing circumstances)</p> <ul style="list-style-type: none"> • Integrate context-awareness in existing construction applications (such as project management applications) to enable intelligent data processing • Address more complex dimensions of the user-context such as context history, work habits, knowledge needs 	

9.7. Closing Remarks

This research has demonstrated that the realisation of the vision of context-aware information delivery is within reach and will tremendously enhance the value proposition of mobile communications in the construction industry. Delivering context-relevant and personalised information to mobile workers will save valuable time and will improve efficiency and productivity. It can also drive the uptake of mobile computing in the construction industry. However, realisation of the real potential of context-aware information delivery in the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. There is a need to integrate technology innovations in other areas, such as multimodal interfaces and speech technologies, to enhance the usability of the mobile devices. Also, a key challenge is to link various technology enabling elements such as those discussed in this thesis with methodological, cultural, social and organisational aspects specific to the construction industry. This would require a multi-disciplinary approach requiring input from different fields, including computer science, ergonomics, social studies and the construction industry. This holistic multi-disciplinary approach is essential to address various facets of context-aware information delivery in the construction industry. Also, to encourage widespread adoption, there is a need for successful industrial case studies. There are numerous potential benefits in providing a context-aware intelligent support infrastructure for mobile workers and the construction industry needs to make the necessary investments to realise these.

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Appendix A: Publications from this Research

- Aziz, Z., Anumba, C.J., Ruikar, D., Carrillo, P.M., Bouchlaghem, D.N. (2005), "Context-aware Information Delivery for On-Site Construction Operations"- 22nd CIB-W78 Conference on Information Technology in Construction, Institute for Construction Informatics, Technische Universitat Dresden, Germany, ISBN 3-86005-478-3, CBI Publication No:304, pp: 321-327
- Aziz, Z., Anumba, C.J., Ruikar, D., Carrillo, P. & Bouchlaghem, D. (2005) "Intelligent wireless Web services for construction—A review of the enabling technologies" *Automation In Construction* – Article in Press [Online] <http://dx.doi.org/10.1016/j.autcon.2005.03.002>
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- Aziz, Z, Anumba, C, Ruikar, D, Carrillo, P, and Bouchlaghem, D, (2003). "Semantic Web Based Services for Mobile Construction Workers", Internal Report, Loughborough University. ISBN: 1 897911 25 4
- Anumba, C.J., Aziz, Z and Ruikar, D.(2003). "Enabling Technologies for Next-Generation Collaboration Systems", *Designing, Managing and Supporting Construction Projects through Innovation and IT Solutions*, Brandon, P, Li, H, Shaffii, N, and Shen, Q (editors), INCITE Conference, Langkawi, Malaysia, February 2004, pp 85-96

Industry Presentations

- Presentation on “Context-Aware Information Delivery For Mobile Construction Workers” at 16th Annual Conference on “The Future of Project Management”, organised by European Construction Institute, The Hilton Hotel, Newcastle Upon Tyne, UK. 18TH March, 2005.
- Presentation on “Context-Aware Information Delivery For Mobile Construction Workers” at COMMIT Project Meeting, Oracle Offices, 7th April, 2005.

Appendix B: System Evaluation Questionnaire

Information About You

Name:

Organisation:

Role in the organisation:

Experience (multiple answers not allowed)

- I have 5 or more years experience of the Construction Industry (This includes your experience of research related to the Construction Industry).
- I will classify myself as a domain expert
- I have previous experience of working on a construction site environment
- I am involved in Construction Research

Details about Your Experience:

Years of Experience:

How would you describe your previous experience of mobile computing in general?

- No experience at all
- Novice/still learning
- Have some experience
- Very experienced

Do you use a mobile device like PDA, Smart Phone for primarily data (non-voice) related purposes?

- Yes
- No
- No, but I plan to start using one

Use Case One- Wireless Project Management

Strongly Agree Agree Disagree Strongly Disagree

Please rate the extent to which the use case satisfies various criteria:

<p>a. I think there is a need for such a system in the construction industry.</p>	1	2	3	4
<p>b. I believe such a system has the potential to offer tangible benefits (such as time and cost reduction) to the construction industry</p>	1	2	3	4
<p>c. I think implementation of such a system in the construction industry faces major barriers (in case if you agree, kindly specify the barriers)</p>	1	2	3	4
<p>d. In my view, the system interface is easy enough for an average construction worker (assuming low technical literacy) to learn and use for his/her daily tasks</p>	1	2	3	4

If you suggest improvements in the prototype demonstrator or if you have any other comments (e.g. usability, relevance, barriers to implementation of such a system), please describe here.