1 Mobile and Pervasive Computing in Construction: an Introduction

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1.1 Background

Generally speaking, the purpose of mobile computing is to provide a computing service to anyone authorized, anytime, anywhere. Simple examples of mobile computing devices which have been widely used by the general public are personal digital assistants (PDAs) and laptops. Projects in the construction industries normally produce a large quantity of information that needs to be accessed by different stakeholders, such as architects, engineers, project managers and superintendents, even foremen. This information usually has to be retrieved in a remote manner from numerous locations inside or outside the construction site, and even under varied conditions. In current practice a field team's project information access and retrieval, information editing and decision making are still limited to 2D paper-based technical drawings and specifications. However, as economics drive the industry towards more digital information management, more information technology (IT) tools are needed for accessing, storing and conveying digital project information (Wang and Dunston, 2006a). Gartner Analysts (2004) predicts that by 2014 more than 30% of mobile workers will be equipped with wearable augmented computing devices. Mobile computing technology holds great potential in this regard and has been explored to improve construction processes (Magdič *et al.*, 2002; Saidi *et al.*, 2002; Hammad *et al.*, 2003; Reinhardt *et al.*, 2004). For example, equipment management in the construction site is a process that monitors the operating condition of equipment, maintains and repairs equipment components and also inputs log data for future access. The current practice of the field crew heavily refers to technical specifications. The field crew often faces the problem of not finding the right information in a convenient and timely manner, which makes this approach labor intensive (Wang *et al.*, 2006). Mobile devices such as the PDA and wearable computers are being explored for storing, conveying and accessing

Mobile and Pervasive Computing in Construction, First Edition. Edited by Chimay J. Anumba and Xiangyu Wang.

information instead of relying on paper media. One of main challenges is the way information is presented by these mobile computing devices, because it is essential to operational effectiveness for the crew and supervisors from the perspective of human factors.

There are many decisions regarding design and implementation that have to be made on the basis of user–computer interactions. Identifying these decision factors should be the first step in fulfilling the maximum potential of mobile computing in construction use. Wang and Dunston (2006) developed a framework for considering feasibility and usability issues of mobile computing technology under varied construction operations and conditions. The objective of this framework is to provide a theory of task–technology mapping for mobile information systems. The work mainly focused on the human factors issues related to hardware devices and collaboration. Other issues, such as strategies for system development, development cost and infrastructure standards, were not considered. Table 1.1 describes mobile computing device capabilities with the "high" and "low" end device examples given.

The field characteristics of construction operations and activities must be considered as well. As shown in Table 1.2, Wang and Dunston (2006) identified the factors in construction task requirements that should be considered when adopting a mobile computing system. Each factor can influence the feasibility and usability of proposed mobile computing systems.

1.2 Fundamental characteristics of mobile computing

The concept of mobile computing is to enable workers to roam seamlessly with computing and communication functionalities in an uninterrupted way. Mobile computing has many constraints that make it different from the conventional office-based desktop computing setup, for example a desktop PC. The followings are the major noted differences (Satyanarayanan, 1996):

- Mobile computing tends to be more resource constrained than its static counterparts. For example, mobile computers used in a large roaming construction site require a source of electrical energy supplied by battery packs. These packs usually cannot last long and need to be charged on a regular basis.
- Mobile computers are vulnerable. Since mobile computers accompany their users everywhere, they are much more likely to be lost, just like the ease with which cell phones are lost. Furthermore, they are more likely to be subjected to rough environments. This is particularly true in a construction site, where the site conditions are usually not safe and involve potential danger to devices.
- Mobile connectivity can be highly unstable in bandwidth and latency. Disconnections often happens in a concrete-framed buildings where construction activities are being carried out.

From the technological standpoint, the following aspects of mobile computing are introduced in this chapter:

Table 1.1 Characteristics of mobile computing device capabilities (Wang and Dunston, 2006)

Device capability	Descriptions	"High" end examples	"Low" end examples
Technical Functionality	Technical features such as limited processing, memory and communication capacities, mobile communication, personal touch, time-critical services (Yuan and Zhang, 2003)	Wearable computers, bluetooth	PDA
Portability	Devices differ in size, weight, performance, storage capacity, display and input mechanism, and other form factors. As a general rule, intuitive user interfaces and simple menu structures should be deployed (Chan *et al.,* 2002).	Pocket PCs, head-mounted display, data glove	Laptop, keyboard, mice
Situational awareness	Includes location awareness and identity awareness. Location awareness refers to situations where information about the location of a user or collaborators is important. Identity awareness refers to situations where the identity of a user or collaborators matters (Junglas and Watson, 2003).	GPS	Paging system, cell phone

- Adaptability
- Mobility management
- Information dissemination and management
- Sensor network
- Security.

1.2.1 Adaptability

As is widely known, living environments have the capability of adapting themselves to the behaviors of human beings. Likewise, adaptability is an inherent feature of mobile computing, because mobile computing devices serve the changing needs of mobile users under varied conditions. Computer scientists, computer engineers, and human factors researchers have long been concerned with how to embed this notion of adaptability into mobile computing devices.

The basic mobile computing architecture is the client–server (CS) model. Typically, servers provide services, such as data retrieval from a database and upload of real-time data, to usually a large group of clients. Conversely, a client dynamically selects the server from which to request the service. There are two ways in which mobile devices can be made adaptable: functionality and data. Adapting functionality means to dynamically change the functions on the

Table 1.2 Profiles of construction tasks (Wang *et al.*, 2006a)

Task profile factors	Profile factor descriptions	Construction cases
Mental requirements	Relevant to perceptual and cognitive tasks involved in performing a construction task. Perceptual tasks are those attributable to sensory comprehension. Cognitive tasks are those involved in the reasoning and volitional processes that translate between perception and action.	Identifying and detecting an object of interest among a cluster of objects could influence the user's focus of attention. There is need for a means of drawing the worker's attention to specific design or construction features.
Physical requirements	The wearing of mobile systems while performing a construction task may increase physical occupancy.	A worker with hand(s) preoccupied by an assembly task may have difficulty in simultaneously using mobile computing systems.
Working environment	Factors include situational awareness requirements, indoor/outdoor location, noise level, work area hazards, working volume etc.	Aural display and speech recognition devices do not work in noisy working environments.
Task difficulty	Refers to the degree of difficulty for performing a task. The difficulty of the task could be as high as strategic planning which is characterized by unstructured decision making and the application of creativity. It could also be as low as operational tasks characterized by the fact that tasks, goals, and resources have been carefully defined.	Upper management involved in the strategic planning routine might need high sophistication of mobile computing devices in every regard, especially the coordination functionalities among different parties.
Task interdependence	The degree to which a task is related to other tasks, and as a result the extent to which coordination with other tasks is required (Thompson, 1967).	Tasks with high interdependence, such as project management, generally require a significant amount of coordination.
Hazards issues	Safety issues can play a role and limit the attention that a user can devote to a mobile system, such as when they are driving a vehicle (Tarasewich, 2003).	If the construction task is to be performed under potentially dangerous conditions, where workers need to keep high situational awareness and update knowledge of the surroundings in real time, the peripheral devices should be wearable enough so that they may not occupy too much of the worker's mobility.
Time criticality	Defined as the importance with which a task needs to be performed promptly (urgency).	Some mobile systems can support urgent tasks by providing the notification of maintenance staff about such emergency situations as equipment breakdown.
Physical disposition	The physical disposition for the work task should be considered in terms of such factors as motion, body position etc. The physical disposition may determine the appropriateness of certain interaction tools or mechanisms.	In a clustered or congested working volume (e.g. HVAC piping corridor or around special equipment), a body-based human–mobile system interaction metaphor is not as appropriate.

applications in response to changes in the operation conditions. For example, in enclosed settings (such as in a concrete-framed building) mobile devices may disconnect easily, whereas during good connectivity outside the building mobile devices depend heavily on the fixed network, which is either located in the construction site or is a public service. Another way to adapt is though varying data fidelity. Fidelity is defined as the "degree to which a copy of data presented for use at the client matches the reference copy at the server" (Noble and Satyanarayanan, 1999). This kind of adaptation is widely accepted as useful in mobile information access applications. One of the important requirements for such applications "ideally, a data item being accessed on a mobile client should be indistinguishable from that available to the application if it were to execute on the server storing the data" (Noble and Satyanarayanan, 1999). Generally speaking, there is a trade-off between higher performance and highest quality information in a mobile computing environment.

1.2.2 Mobility management

Maintaining the current location of every mobile device is location management. Conceptually, a mobile location management scheme consists of two operations: search and update (Pitoura and Samaras, 1998). The search operation is usually triggered by one computing device trying to make a connection with another mobile computing device with unknown location. The update operation is to update the system with the current location of each mobile computing device. Such an update operation can enable a more efficient search operation.

Location information can be maintained at various fidelity levels or granularities. If the location information is maintained at a coarser granularity, for example in a construction field site which only contains a limited number of cells, the computing cost associated with searching increases because any time that a cell needs to be created, most of other cells have to be called upon to determine the exact location of the mobile computing device. On the other hand, in a basic cellular system a cell is the finest granularity which is maintainable. The way the location information is updated is to transit information from one cell to the other as the mobile devices move. Always the nearest cell is recognized to provide the update of the location information. Therefore, the granularity has a lot to do with the accuracy and frequency of location information.

1.2.3 Information dissemination and management

Accurate and in-time information is critical for the daily work on a construction site. Some information can be distributed via email, telephone calls and so on. Some information can be request-on-demand. Every time information is needed, an inquiry is sent through mobile computing devices to an information resource or provider. Certainly, every time this back and forth communication occurs there will be an associated cost, either monetary or in-kind.

The most common use of mobile devices in construction is to access information on remote data or file servers. For example, Building Information

Models (BIM) have much potential to be located in file servers to be downloadable. The client sends an inquiry to the server and then waits for responses. Then the server sends the requested data as a response to the client. In this process, apparently both the computing power and the wireless bandwidth are consumed. More resources will be occupied and consumed if a large number of clients access the server and the size of data transferred is large as well. This is a very typical phenomenon in a construction site, where you have many different types of mobile personnel working on different activities. All have to access different types of information from the server and usually the information needed is large.

1.2.4 Sensor networks

Wireless networks of smart sensors have become feasible for many applications because of technological advances in semiconductors, energy efficient wireless communication and reduced power budgets for computational devices, as well as the development of novel sensing materials (Akyildiz *et al.*, 2002). The following are the common properties of the sensor networks:

- Sensor nodes are usually designed to directly interact with the physical world and to perform computational tasks based on the confirmation gathered from the surrounding environment (Estrin *et al.*, 2001).
- Usually they are special purpose devices, such as biological sensors, thermal sensors, acoustic sensors vibration sensors, light sensors, chemical sensors and magnetic sensors.
- It becomes a special challenge that there usually are very limited resources in wireless computing which have limited communication bandwidth. These resources have to be shared among numerous sensors.
- There needs to be a specialized routing pattern to enable the communication to occur between sensors at adjacent levels.

1.2.5 Security

Security is a critical issue in mobile computing as it concerns the interested parties using the technology. There are different aspects of security in mobile computing. There are four common security issues (Schneier, 1996):

(i) System integrity or data integrity: a system provides integrity if it performs its intended function in an unimpaired manner, free from deliberate or inadvertent unauthorized manipulation of the system.
(ii) Confidentiality: data are provided when only intended recipients can read the data.
(iii) Nonrepudiation: it is a property of data and means that the sender should not be able to falsely deny sending the data. This property is important for e-bidding in construction procurement, because owners do not want contractors or subcontractors to be able to deny that they had bid with a price.

(iv) Availability: it is a property of systems where a third party with no access should not be able to block legitimate parties from using a resource.

1.3 Pervasive computing

Weiser (2002) described a pervasive computing world in which virtually every object has processing power with wireless or wired connections to a global network. The term pervasive computing also goes by the name *ubiquitous computing* and has very close relationship in technical implementation with *mobile computing.* Mobile computing is a necessary component of pervasive computing. This is why there are many common research interests across these two areas and technologies. Maybe one of the most unique features of pervasive computing is invisibility (i.e. being embedded into objects everywhere). There are many prominent concepts created based on pervasive computing; for example, smart cities, smart homes, smart cars and so on. One the most reputed examples is Digital Cities, which is a concept that inhabitants in cities can interact and share knowledge, interests and life experience. For example, the city of Lancaster in the United Kingdom used wireless devices to improve services for both visitors and residents based on Wi-Fi applications. Kyoto, Japan, is another example in which the digital city complements and corresponds to the physical city (Ishida, 2002). Pervasive computing could have a range of applications, many of which may not yet have been identified. Applications exist in environmental monitoring, healthcare, domiciliary care and intelligent transportation systems.

Pervasive computing has considerable potential in the built environment, just as many other emerging and prominent technologies have. For example, a mobile worker should be able to access the procurement or inventory information of a specific type of construction material at a nearby location without necessarily having to connect to the office service via a network. All they may need is a local embedded information service onto the piece of material. This can help workers access these resources without having to reconfigure their devices. The facility manager can monitor the building's equipment use and energy consumption status through reports. Data can then be analysed based on dimensions such as time, the type of equipment and use conditions to reveal the trends of use as well as giving suggestions of how to use them in a more efficient way.

1.3.1 Pervasive computing technologies

Pervasive Computing Devices

The forms and sizes of pervasive computing devices vary. They can range from mobile phones to computing units embedded into normal and daily objects, such as clothing and books. Examples of objects and devices include barcodes, e-tags, RFID, PDAs (personal digital assistants) and laptops with sensing capacities, and information appliances such as digital cameras. Pervasive computing also uses internet and wireless communications. A global wireless connection like a mobile phone is not always required. The devices of pervasive computing could interact with each and with the users. Or even made invisible!

Some of these devices function as sensing devices that can recognize changes in the context; for example, the changes from the surrounding environment, human behaviors and so on. Some devices function by reasoning and interpreting the behaviors or changes from outside based on continuously sensed data input. Some devices function as output that can trigger or initialize an effect on the surrounding environment or objects.

Human–Computer Interfaces

Novel human–computer interfaces are needed to meet the requirements of the pervasive computing. The conventional mouse, keyboard and monitor will not work anymore. Future interfaces will be interactive, user friendly and embedded into objects. Augmented Reality (AR) is very promising as an effective visual information tool, as it can insert the digital information directly into the user's real world view. This concept is coincident with pervasive computing, as both of them rely on daily physical objects as the information embedding vehicles. Other interfaces should extensively consider multisensory channels, such as audio, haptic, smell and so on, as they are all related to our daily life.

Privacy and Security

The privacy and security issues in pervasive computing are the same as for mobile computing. There is scope to access users' everyday interactions, movements, preferences and attitudes, without user intervention or consent; and to retrieve and use information from large databases of stored data; alter the environment via actuating devices (EU Directive, 1998). There are three areas that are the most popularly researched issues (IST, 2005):

(i) keeping the volume of transmitted data to a minimum;
(ii) encrypting and sending anonymously data that require transmission;
(iii) treating security as a continuing and integral element of pervasive computing.

Context Awareness in Pervasive Computing

What the context means in mobile and pervasive system has been explained. Context awareness refers to capturing a broad range of contextual attributes to better understand what the consumer needs, and what products or services he or she might possibly be interested in (Sadeh, 2002). Context awareness is part of contextual computing, which refers to the enhancement of a user's interactions by understanding the user, the context and the applications and information being used, typically across a wide set of user goals (Pitkow *et al.*, 2002). Context-aware pervasive computing system involves the following issues:

- How is context defined and represented?
- How is this context information combined and stored within the pervasive application?

- How often should the data on context be collected and reasoned upon?
- What is the nature of the services that a surrounding environment needs to provide to realize context awareness?

1.4 Summary

This introductory chapter has covered the basic aspects of mobile and pervasive computing in construction, introducing the factors that should be considered in human–computer interaction, the factors in construction site operations and activities that should be considered and also the fundamentals and principles of mobile and pervasive computing. It has prepared audiences to better understand the paradigms, theories, metaphors in the other technical chapters in this book.

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