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MOBILE AND PERVASIVE COMPUTING IN CONSTRUCTION

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Contents

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Preface

In the recent past a variety of research has explored the possibilities of mobile and pervasive computing. Mobile and pervasive computing technologies play an increasing role in architecture and construction. From a review of work in similar areas, it was found that there is no publication that focuses on mobile and pervasive computing in construction. Mobile and pervasive computing systems were conventionally developed by computer experts with limited appreciation of the real needs in architecture, construction and the built environment. However, more researchers are now applying mobile and pervasive computing in the construction sector and there is the need for a book that summarizes the current state-of-the-art for both researchers and industry practitioners. The objective of the book is to introduce the use of mobile and pervasive computing in construction through a discussion of construction issues and the applications that seek to address them. The book is a research-oriented reference book that not only acts as meta-book in the field to define and frame mobile and pervasive computing for construction industry but also addresses up-coming trends and emerging directions of the field.

This book offers a comprehensive reference volume to the state-of-the-art in the area of mobile and pervasive computing in construction. It is based on contributions from a mix of leading researchers and experts from academia and industry. The book provides up-to-date insights into the current research topics in this field as well as the latest technological advancements and the best working examples. Many of these results and ideas are also applicable to other industry sectors. Predominantly, the chapters introduce recent research projects on the theories, applications and solutions of mobile and pervasive computing for construction. More specifically, the central focus is on the manner in which these technologies can be applied to influence practices in construction and construction-related industries.

Overall, this book offers an excellent reference for the postgraduate students, the researchers and the practitioners who need to understand the potential of mobile and pervasive computing in construction.

The book starts with Chapter 1, *Mobile and pervasive computing: an Introduction*, by Chimay Anumba and Xiangyu Wang, which gives an overview on the fundamental technical and social issues of mobile and pervasive computing and their impact on the construction industry. This overview sets the context and frames the scope of the book. It discusses how mobile and pervasive computing has led to new ways for engineers and constructors to carry out their operations.

Chapter 2 by C. Anumba, Z. Aziz and D. Ruikar, *Mobile and Semantic Web-based Delivery of Context-Aware Information and Services in Construction*, describes the context and methods for deployment of mobile and semantic web-based context-aware services in the construction sector.

J. Delsing, in Chapter 3, *Communication technology in mobile and pervasive computing*, discusses how the concept of mobility and pervasiveness can be applied to industrial applications and discusses three different classes of mobile and pervasive devices.

As for using mobile computing technologies in different construction on-site training schemes, Chapter 4, *A Framework for Designing Mobile Virtual Training System through Virtual Modeling Technology*, by X. Wang *et al.*, presents a systematic taxonomy formulated to identify some of the distinctions; it distinguishes between some of the constraints imposed by different training scenario environments and is applicable to the design of mobile virtual training programs.

A. Behzadan, S. Dong and V. Kamat describe and demonstrate, in Chapter 5, *Mobile and Pervasive Construction Visualization using Outdoor Augmented Reality*, the ability of the ARVISCOPE animation authoring language to create pervasive dynamic AR animations of construction operations. Although the main focus of this chapter is on construction processes, most of the findings of this research are generic and widely applicable to other fields of science and engineering where the need to animate and communicate simulated operations is as important as that in construction.

Chapter 6, by H. Khoury, M. Akula and V. Kamat, *Ubiquitous User Localization for Pervasive Context-Aware Construction Applications,* studies several tracking technologies, and designed methods and algorithms to track mobile users in congested environments such as those found on construction sites. The research described presents GPS technology and compares three different wireless technologies (WLAN, UWB and Indoor GPS) that can be used for tracking mobile users' position on outdoor and indoor construction sites.

Sophisticated personal context-aware assistance is also critical to the success of mobile computing in construction. Chapter 7, by D. Rebolj and A. Magdič, *Person-oriented mobile information system enhancing engineering communication in construction processes*, proposes an approach focusing on people and effective linking of their knowledge, experience and capability. Also presented are two case studies and a social network analysis that was used to validate the approach.

On-site information retrieval is critical to aspect of mobile computing in construction. *The iHelmet: an AR-enhanced* *wearable display for BIM information*, by K. Yeh, M. Tsai and S. Kang (Chapter 8), describes a wearable device named the iHelmet that can project construction drawings and related information on the site, answering to the needs of the users. The authors believed that the AEC industry may benefit from the iHelmet's improved efficiency in browsing information and its offer of more visualized information to the user.

As an effort to study how designers learn design in Collaborative Virtual Environments (CVEs), in Chapter 9, *Mobile and Pervasive Computing: The Future for Design Collaboration*, M. Kim, M. Maher and N. Gu report on their experience of teaching the design of virtual worlds as a design subject, and discuss the principles for designing interactive virtual worlds.

The automated detection of structural elements from visual data can be used to facilitate many construction and maintenance applications. Chapter 10, by I. Brilakis, *Visual Pattern Recognition Technologies for Mobile Systems at Construction Site*, explores and compares different approaches for construction site surveying, which is a very critical technological component for effective mobile and pervasive computing platforms.

In Chapter 11, *Structural Health Monitoring using Wireless Sensor Networks*, J. Cao and X. Liu give a summary review of the recent advances of using wireless sensor nodes for structural health monitoring. Instead of listing the hardware prototypes and software design of existing wireless sensor network-based structure health monitoring systems, the chapter identifies the main challenges of using wireless sensor network-based structure health monitoring systems and also summarizes the corresponding techniques.

Chapter 12, *Cloud Computing Support for Construction Collaboration*, by J. Cheng and B. Kumar, discusses the potential and implication of cloud computing technology in the construction industry to facilitate communication and collaboration among distributed construction project stakeholders. A distributed cloud-based collaboration model that is designed for construction collaboration and management is proposed.

The final chapter, by Chimay Anumba and Xiangyu Wang, provides some concluding notes by highlighting the benefits, challenges and future directions in the adoption of mobile and pervasive computing in construction.

Chimay Anumba and Xiangyu Wang

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Professor Chimay J. Anumba
Professor Xiangyu Wang

Chapter 1

Mobile and Pervasive Computing in Construction: an Introduction

Chimay J. Anumba and Xiangyu Wang

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 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.

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

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.

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

Task profile factors	Profile factor descriptions	Construction cases

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.

Task profile factors	Profile factor descriptions	Construction cases
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.

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:

- 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 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.