REAL TIME MOBILE INFORMATION SYSTEM FOR CONSTRUCTION PROGRAMME MANAGEMENT

Mohamad Syazli Fathi[1], Chimay Anumba [2], Patricia Carrillo [3] and Mohd Zulakhmar Zakiyudin[4]

[1]*Department of Civil Engineering, College of Science and Technology, UTM International Campus, Jalan Semarak, 54100 Kuala Lumpur, Malaysia*
[2]*Department of Architectural Engineering, The Pennsylvania State University, University Park, PA 16802, USA*
[3]*Department of Civil and Building Engineering, Loughborough University, LE11 3TU, United Kingdom*
[4]*Lecturer, Faculty of Architecture and Built Environment, International University College of Twintech, Bandar Sri Damansara, 52200 Kuala Lumpur, Malaysia*
syazli@ic.utm.my

ABSTRACT

The complexity and information-intensive nature of construction programmes require Programme Managers to access construction information in real-time and when needed. The increasing use of mobile devices, such as PDAs, offers an opportunity to meet this need. However, access to information and services on mobile devices is often limited by their capability and the network coverage and bandwidth. This creates problems in accessing the right information at the right time, especially when spontaneous and/or urgent decision-making is needed. Decision-making can be improved by delivering information and services to Programme Managers via their mobile devices in real-time and based on their context.

This paper reviews the challenges and issues in the delivery of information in construction programme management and explores how context-aware computing can help in managing information and services in a construction programme. The key issues in context-awareness in construction programme management are discussed and the enabling information and communication technologies described. The context of a user (such as role, location, time, preference, etc) can be utilised to provide personalised information. Wireless communication technologies allow computing and communication devices to be used virtually anywhere in delivering information and services. The discussion in the paper focuses on the potential application of context-aware computing in construction programme management using wireless devices. Conclusions are drawn about the possible implementation of these emerging context-aware computing technologies for Construction Programme Managers in Malaysia.

Keywords: Mobile Information Systems, Context-Aware Information Delivery, Construction Programme Management, Wireless Communication,

1. INTRODUCTION

Construction is an information intensive industry (Anumba et al., 2008), and as such, information delivery is the key to better management, survival and success. Researchers have estimated that if this information could be managed effectively then savings of up to 25% in the construction cost could be achieved (Baldwin et al., 1999). Furthermore, construction activities are widely dispersed and site locations are frequently changed (Magdic et al., 2002) complicating the management of the multiple-projects. Modern project management methods and tools have evolved tremendously in order to overcome problems in construction management. The use of project management tools in construction management has been widely known (Milosevic, 2003). However, with the growing complexity of single and multi-construction

projects, the traditional methods of construction management need to be revised by using construction programme management. Construction programme management deals with the integration and management of multiple-construction projects and complex resources utilisation with the intent of achieving benefits that would not be realised if they were managed separately.

It has been suggested by researchers (Aziz et al., 2006) that by using wireless communication technologies, the information, communication and services delivery between project team members in the field and the office can be enhanced to be in real time. Thus rapid decisions can be made by the construction programme manager. The primary goal of the construction programme manager is overall control of all aspects of the construction programme. This includes the pre-design planning, programming of requirements, pre-design budgeting, design, construction, equipping, furnishing, commissioning, occupancy and close-out of the project.

Researchers (May et al., 2005, Aziz et al., 2006) however claimed that the existing mobile applications in the construction industry only support the communication of static information (such as project data, plans, drawings, etc.), and are unable to take into account the construction worker's changing context and the dynamic project conditions. Similarly, most of the commercially available mobile applications for construction management are designed primarily to deliver pre-programmed project management tools without any consideration of the Construction Programme Manager's context. This often leads to irrelevant and inadequate information supplied to the Construction Programme Manager.

Context-aware computing is an intelligent system that uses environmental characteristics such as contextual elements of a user's location, time, identity, and activity to inform the computing device of its current context (Burrell and Gay, 2001). Context-aware computing applications examine and react to a user's changing context in order to help promote and mediate people's interactions with each other and their environment (Schilit et al., 2002). In addition, some have the ability to provide highly specific data and services by intelligent interpretation of their context (Aziz et al., 2006). It is suggested that awareness of a user's context (such as user role, task, preferences, location, site conditions, etc.) in mobile construction applications will enhance the effectiveness of programme delivery by providing information and services relevant to a particular context.

Firstly, this paper reviews the key issues in construction programme management. Secondly, it explores how context-aware computing can help construction programme managers in managing construction projects more effectively. It also discusses the enabling information and communication technologies. Thirdly, the prototype application development are then presented and discussed. Finally, a number of conclusions are drawn.

2. CONSTRUCTION PROGRAMME MANAGEMENT

A construction programme usually requires an expanded scope of construction management services, which is commonly referred to as construction programme management. Construction programme management services normally focus on managing the planning, design and construction of a building programme involving multiple projects and multiple phases on either a single site or on multiple sites. The Construction Programme Manager (CPM) is responsible for the overall projects (within the programme), including awarding contracts, procuring materials, monitoring costs and schedules and managing the necessary reporting and communications.

Construction project and programme management have been used to build some of the greatest engineering achievements, from the Petronas twin tower to complex structures such as Beijing Olympic Stadium. In part, this success can be attributed to the construction project managers' focus and discipline inherent in project management, and the integration and coordination of such complex initiatives facilitated by the construction programme manager in a programme management framework.

Programme management provides a bridge between projects and the organisation's strategy, they must be both adaptable and forceful, absorbing shocks and discontinuities yet ensuring that progress is achieved (Pellegrinelli, 2002). The construction programme manager needs to act like a strategic manager, using a wide range of skills and competencies to realise lasting organisational changes in the face of

vested interests and cultural diversity. From a strategic management perspective, an organisation requires flexibility to shape and respond to its own environment.

There are several reasons why project management tools are inappropriate to the current context of construction programme management. The management of a multi-construction project and that of a construction programme differ in the following areas (Table 1): -

Table 1: Comparisons between Construction Project and Programme Management

Description	Construction Project Management	Construction Programme Management
Designation	Project Manager	Programme Manager
Responsibility (Pellegrinelli, 1997)	Project manager has single point responsibility for project's success	Programme manager facilitates the interaction of numerous managers
Stakeholder (Lycett *et al*., 2004)	Specific for the whole duration of the project	Come and go over the course of a programme – more flexible and adaptable
Objectives (Pellegrinelli, 1997)	Has set objectives	Evolves in line with business needs
Project Delivery or Outcome (Pellegrinelli, 1997)	Single delivery	May involve the management of multiple, related deliveries
Duration (Pellegrinelli, 1997)	Fixed duration	May have an indefinite time horizon
Capability (Tanaka, 2005)	Overview of a single project	Overview of multiple projects
Optimisation	Self-centred optimisation	Cross-division overall optimisation
Management Type	All-round management	Management by priority and focus
Skill (Tanaka, 2005)	Project Management Skills	Hybrid skill of project management and general management skills
Planning	Specific for single project planning	Multiple project planning to integrate in programme planning
Resources	Resource utilisation from the allocation for a specific project	Interdependencies in term of resources utilisation
Output (Lycett *et al*., 2004)	End with completion or sign-off of project deliverable	Has overall responsibility for ensuring benefits realisation

The fact is that today's construction programme manager must execute a programme effectively with two drivers that are in a constant state of change: (1) people; and (2) technology.

- People (for a variety of reasons), come and go in today's business or construction environment. Therefore, the organisation must have the ability to expand and contract on a rapid basis and react to changes in the marketplace. The ability to acquire people rapidly and to enable them to make a valuable contribution quickly is a necessity for survival in today's marketplace (Brown, 2008).
- Technology that changes rapidly. The programme manager must also deal with constant changes in technology. As technology changes, every company has opportunities to improve operations (Archibald, 2003).

A core element of programme management is tracking the progress of projects and taking action (Pellegrinelli, 1997). Effective and efficient project deliverables are creating competitive advantages for the organisation (in monitoring and controlling the construction programme). Therefore, tools are needed to support construction programme managers in monitoring, controlling and making an informed decision in construction programme management. This support is provided through real time mobile information

system that have the capabilities in the supplying and managing large amounts of information, so decision makers can make informed decisions based on the most important facts.

3. MOBILE INFORMATION SYSTEMS

A mobile information system is one in which access to information resources and services are gained through end-user terminals that are easily movable in space, operable no matter what the location and, typically, provided with wireless connections (Pernici, 2006).

Currently, mobile devices are used to access all sorts of information and are becoming a major means of accessing information and services, either client or web-based applications. The widespread use of mobile devices, in domains like mobile work, mobile learning and the emergency services envisions a growing market for new applications (Thurnher *et al*., 2006). Mobile devices and wireless technology are also being upgraded and are thus providing applications with a variety of functionalities along with better levels of service.

The concept of using mobile applications and applying Wireless Local Area Network (WLAN) technology to the construction site is not new. Mobile applications and WLAN technology were identified by many researchers (Garzaa and Howitt, 1998, Aziz et al., 2005, Bowden et al., 2006, Chen and Kamara, 2008, Šuman and Pšunder, 2008) as a viable solution to the problem of real-time data capture on construction sites. They cited the main advantages as being the mobility and value added (no service provider charge and higher data transfer rates than other technologies). Magdic et al. (2002) and Pernici (2006) also agreed that the advantages of mobile information systems are not just their ability to provide cost-effective services but also new value-added services owing to their mobility and flexibility (with respect to the context of use). The rapid developments in mobile and wireless ICT and mobile devices have now enabled the new possibilities of portability and on-demand access to information systems and communication tools that construction organisations are requesting (Löfgren, 2007).

The construction programme manager typically moves between physically different locations, further complicating the accessibility and transmission of critical project and programme information. It is well understood that the use of mobile information and communication technologies (ICT) is critical in managing construction projects as the right information needs to be delivered to the right person, at the right time and at the right place (Bowden *et al*., 2006). However, the existing mobile applications in construction programme management only support the delivery of static modes of information such as project data, technical drawings, risk assessment etc, they are pre-programmed and thus not able to take into account the workers' changing context and the dynamic project conditions (Aziz, 2005).

This research focuses on a new interaction paradigm for a construction programme manager by supplying specific information to a specific individual at a specific time and at a specific place.

4. CONTEXT-AWARE COMPUTING

Context is a powerful and longstanding concept in human-computer interaction. Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use in a social context, and with the study of major phenomena surrounding them (Ghaoui, 2006). Interaction with computation is by explicit acts of communication (e.g., pointing to a menu item) and the context is understood (e.g., default settings). Context can be used to interpret explicit acts, making communication much more efficient (Ghaoui, 2006).

The use of context-aware computing technologies enables mobile applications to deliver context-specific information and services to the user. According to Aziz (2005), the use of context-aware information delivery is able to eliminate distractions for the users (related to the volume and level of information). Context-aware computing also enhances the use of mobile information systems in construction programme management by not just providing a filtering mechanism (to deliver information relevant to the task at hand) but also by increasing efficiency and integrity (being able to make an informed decision). Context-aware computing also has the potential to increase usability by decreasing the level of interaction required between a mobile device and the user (Aziz *et al*., 2005).

It is important to note that mobile context-aware application is also gaining interest in the architecture, engineering and construction (AEC) industries. Many potential applications have been demonstrated for the construction industry, such as resources requirements at the construction site (Singhvi et al., 2003), disaster management system (Zreik and Parfouru, 2005), collaboration at the construction site (Aziz et al., 2006), information delivery for construction site workers (Aziz, 2005, Behzadan et al., 2008), and information delivery for construction management (Fathi *et al*., 2006). Several models and system architectures for context-aware computing in Architecture, Engineering and Construction (AEC) have also been developed and reported (Singhvi et al., 2003).

One of the most important dimensions and commonly used context attributes in context-aware computing is based on location. According to Smailagic et al. (2001), many frameworks have been developed utilising the location context. In published mobile computing research (Pagonis and Dixon, 2004, Pashtan, 2005), the location parameter is most often used to approximate the context and to implement context-aware applications. Mobile computing applications characterised by devices that are operational and operated while on the move (e.g. PDA-phones, mobile phones), can significantly benefit from a context location. This section presents, classifies and reviews the enabling technologies to determine the context location. It also compares location tracking technologies to determine their applicability to the research.

According to Bonsor (2001), a location-based service system will use a combination of Geographic Information Systems (GIS) with any location-tracking technology such as Global Positioning System (GPS), Radio Frequency Identification (RFID) and Wireless Local Area Network (WLAN) technologies. Geographic data is an important aspect of any location system. Geographic Information Systems (GIS) provide the tools to provision and administer base-map data such as manmade structures (streets, buildings) and terrain (mountains, rivers). GIS is also used to manage point-of-interest data such as location of petrol stations, restaurants, hotels, etc. GIS information also includes information about the radio frequency characteristics of the mobile network. This allows the system to determine the serving cell site of the user.

A variety of different location tracking technologies can be found with significantly different characteristics, usage, infrastructure and device requirements. Location-tracking technologies can be classified as micro (location-tracking in an indoor environment), macro (location-tracking in an outdoor environment) and hybrid (a combination of micro- and macro-location-tracking technologies). The competing location tracking technologies are briefly reviewed in Table 2.

Table 2: Location Tracking Technologies

Technology	Brief Description
Wireless Local Area Network (WLAN)	Network of devices that connect via radio frequency, such as 802.11b. These devices pass data over radio waves and provide users with a network with a range of 70 to 300 feet (21.3 to 91.4 meters).
Global Positioning System (GPS) (Oloufa *et al*., 2003)	Global Positioning System (GPS) receives signals from multiple satellites and employs a triangulation process to determine physical locations with an accuracy of approximately 0.5 - 5m (commercial use). However, GPS is inefficient for indoor use or in urban areas where high buildings shield the satellite signals.
Time Difference of Arrival (TDOA) (Aatique, 1997)	The Time Difference of Arrival (TDOA) technique is one of the position location techniques for cellular-type wireless communication systems. TDOA techniques are based on estimating the difference in the arrival times of the signal from the source at multiple receivers.
Active Badge Infrared (Want et al., 1992)	An Active-Badge system uses infrared emissions from a small infrared badge, carried by the object of interest. A centralised server receives the emitted signals and provides the location information.
Radio Frequency Identification (RFID) (Bahl and Padmanabhan, 2000)	RFID is a small and battery-less microchip that can be attached to consumer goods, animals, equipment and other objects to track their movements. RFID tags are passive and only transmit data if prompted by a reader. The reader transmits radio waves that activate the RFID tag. The tag then transmits information via a pre-determined radio frequency. This information is captured and transmitted to a central database.

Table 3 shows the advantages and disadvantages of the technologies in terms of the coverage area and availability for use in developing an application. This comparison also shows that GPS and WLAN technologies have better features and have great potential for combining the technologies for mobile-application development. This is due to the coverage area and enabling features such as there being no need for either an antenna or line-of-sight (which the signal is not required to travel in a straight line to function), which is important for mobile applications where users are moving back and forth from an indoor to an outdoor environment.

Table 3 : Competing Technologies

	WLAN	GPS	Passive RFID	Active RFID	TDOA	Infrared
Global	X	√	X	X	X	X
City-wide	X	√	X	X	X	X
Campus-wide	√	√	X	√	√	X
Indoor, room level	√	X	√	√	√	√
No need for antennas/readers	√	√	X	√	√	X
No need for line-of-sight (travelling in a straight line)	√	√	X	X	X	X

5. PROTOTYPE DEVELOPMENT

The concept of supplying specific information and services to the construction programme manager has become technically and financially feasible because of the capability of integrating mobile devices, context-awareness, data, voice and positioning technologies. Although on a small scale, research works by Aziz et al.,(2006) and Fathi et al.,(2006) proved that the concept was achievable and functioning in real-time.

5.1 System Architecture of the Prototype Application

Based on the literature (Imielinski and Viswanathan, 1994, Voelker and Bershad, 1994, Abowd et al., 1997, Brown et al., 1997), design goals and users requirements identified, the researcher developed a system architecture for the design of context-aware information and services tool for the Construction Programme Manager as shown in Figure 1.

The context-aware information system (C-aIS) architecture consists basically of four main components: -

1. The **Positioning System** – using GPS and WLAN for the determination of the current location;
2. The **Mobile Client** – a mobile device that is able to received location coordinates from GPS and WLAN, transmit location coordinates to the application server, receive information or data from the server and the CAIS application that is able to process the selection between GPS and WLAN location information (C-aIS Client Engine);
3. The **Context Information Network System** – the wireless network environment for transmitting contextual information and data to the users; and
4. The **Server System** – the context-aware server engine that is able to process location data gathered from GPS and WLAN and intelligently choose the right information and services from the servers available in the system such as the Database server, the GIS server and the Enterprise Project Management server.

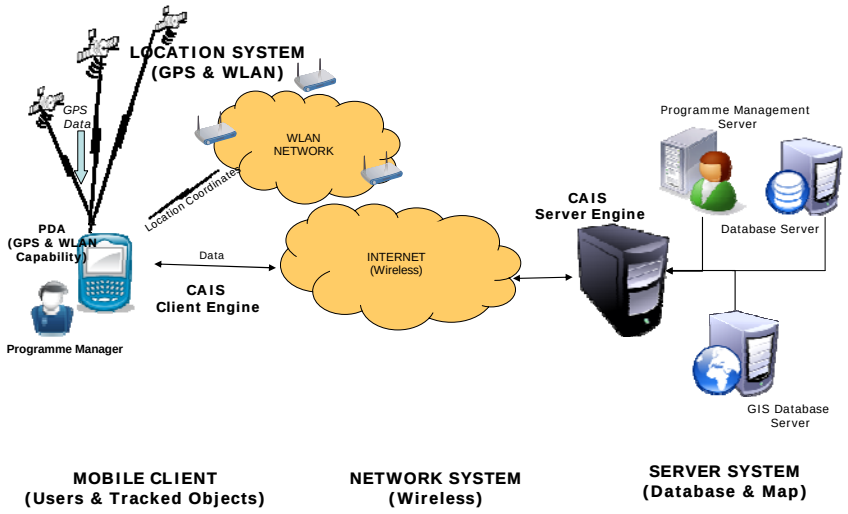

Figure 1 : Context-Aware Information System (C-aIS) Architecture

Having context-aware applications (such as the location and activity context) allows the application to present information and services that are relevant to the Construction Programme Manager's current position, especially when the Programme Manager makes multiple site visits. The context-aware application supplies information and services based on the Construction Programme Manager's current location by using the Global Positioning System (GPS) for the outdoor location coordinates and a Wireless Local Area Network (WLAN) for the indoor location coordinates. The location coordinates (latitude, longitude and altitude) are then transmitted from the mobile client (PDA-Phone with GPS and WLAN capabilities) to the C-aIS application server through a wireless network.

The C-aIS application server registers the query issued by the mobile client and then performs the following operations until the query is active:

1. Retrieve information associated with the current context together with its scope and load information to the user's device (based on selected context information); and
2. Periodically monitor the current user's context and check whether it belongs to the current information scope. If an out-of-scope condition is detected, the service manager restarts from step 1.

The C-aIS application server will process the coordinates received based on the context defined (such as location, time, activity, task and project). This process will involve the programme management servers, database servers and GIS servers, so that it can be programme to automatically send specific information and services to the Construction Programme Manager (such as the project information required, issues to be resolved at the project site, advice, coordination or overall overview of the project) based on the context information. This flow of project information and services can be utilised by the Construction Programme Manager to monitor a programme's performance, progress reports and efficiently manage a multiple-project environment.

5.2 Features of the Prototype Application

The prototype application have been developed to have several key features such as; real time context-aware project and programme dashboard, real time information on the status of materials and issues on sites, various real time context-aware services, and context-aware searching capabilities.

Figure 2: Features in the prototype application

The management of a programme (or multiple projects) presents challenges that are different from those of single-project management. The situations are complex (unpredictable and non-linear) (Aritua *et al.*, 2009) and information requirements are huge (to cover the macro- and micro-levels) (Fathi *et al.*, 2007). Thus, designing and developing mobile context-aware construction programme management applications is challenging and demanding. The technology itself is rather complex and involves several fields and technologies that contribute to the final outcome (such as integration, system architecture and interaction design).

The concept delivers benefits to the organisation through a new way of managing projects and programmes, which in turn delivers to the construction programme management the benefits of high efficiency, good visibility and good governance. Context-specific information and service delivery should be supplied not just to the construction programme manager, but also to other project team leaders so that they are able to make informed decisions.

6. CONCLUSIONS

This paper has given an overview of the mobile information systems which are supported by a broad range of computing and communication technologies, including context-aware computing and location-tracking technologies (such as GPS, WLAN). The review also shows the potential of real time mobile information system for construction programme managers. This paper shows that, to develop mobile context-aware application for construction programme managers, the system should be able to integrate multiple technologies such as context-aware computing, mobile device, GPS, WLAN and enterprise project management system in real time. These technologies will be taken forward in this research.

Technology itself would not guarantee success if the system was unable to meet the needs of the user. Therefore, it is important to understand the relationship and interaction between the user (human) and the application (computer) before developing any computer application. The success of the application depends on the right research philosophy, methodology and techniques. This will be the focus of the other research papers.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Teknologi Malaysia and the Ministry of Higher Education, Malaysia for sponsoring this research.

REFERENCES

Aatique, M. (1997) *Evaluation of TDOA Techniques for Position Location In CDMA Systems*. Master of Science In Electrical Engineering, Faculty of the Electrical Engineering, Virginia Polytechnic Institute and State University

Abowd, G. D., Atkeson, C. G., Hong, J., Long, S., Kooper, R. and Pinkerton, M. (1997) Cyberguide: A Mobile Context-Aware Tour Guide. *ACM Wireless Networks,* 3 (5), pp.421-433.

Anumba, C. J., Pan, J., Issa, R. R. A. and Mutis, I. (2008) Collaborative Project Information Management In A Semantic Web Environment. *Engineering, Construction and Architectural Management (ECAM),* 15 (1), pp.78 - 94.

Archibald, R. D. (2003) *Managing High-Technology Programs and Projects*. 3rd ed.: John Wiley and Sons

Aritua, B., Smith, N. J. and Bower, D. (2009) Construction Client Multi-Projects - A Complex Adaptive Systems Perspective. *International Journal of Project Management,* 27 (1), pp.72-79.

Aziz, Z. (2005) *Context-Aware Information Delivery for Mobile Construction Workers*. PhD Thesis, Civil and Building Engineering, Loughborough University

Aziz, Z., Anumba, C. and Law, K. (2006) Using Context-Awareness and Web-Services to Enhance Construction Collaboration, In: Rivard, H., Melhem, H. & Miresco, E.(Eds.), *Joint International Conference on Computing and Decision Making in Civil and Building Engineering.* ASCE, 14-16 June, In Rivard H., Melhem H. & Edmond Miresco (Eds.), 14-16 June 2006a, Montreal, Canada. pp.3010-3019.

Aziz, Z., Anumba, C. J., Ruikar, D., Carrillo, P. M. and Bouchlaghem, N. M. (2005) Context Aware Information Delivery for On-Site Construction Operations, *22nd CIB-W78 Conference on Information Technology in Construction.* Institute for Construction Informatics, 19-21 July, Technische Universitat Dresden, Germany. pp.321-327.

Bahl, P. and Padmanabhan, V. N. (2000) RADAR: An in-Building RF-Based User Location and Tracking System, *In Proceedings of the IEEE Infocom 2000.* 26-30 March, Tel-Aviv, Israel. pp.775--784.

Baldwin, A. N., Thorpe, A. and Carter, C. (1999) The Use of Electronic Information Exchange on Construction Alliance Projects. *Automation in Construction,* 8 (6), pp.651-662.

Behzadan, A. H., Aziz, Z., Anumba, C. J. and Kamat, V. R. (2008) Ubiquitous Location Tracking for Context-Specific Information Delivery on Construction Sites. *Automation in Construction,* 17 (6), pp.737-748.

Bonsor, K. (2001) *How Location Tracking Works.* [online] Atlanta, GA: HowStuffWorks.com Available from http://people.howstuffworks.com/location-tracking.htm/printable [Accessed 25th January 2009]

Bowden, S., Dorr, A., Thorpe, T. and Anumba, C. (2006) Mobile ICT Support for Construction Process Improvement. *Automation in Construction,* 15 (5), pp.664-676.

Brown, J. T. (2008) *The Handbook of Program Management: How to Facilitate Project Succss with Optimal Program Managment* New York: McGraw-Hill Professional

Brown, P. J., Bovey, J. D. and Chen, X. (1997) Context-Aware Applications: From the Laboratory to The Marketplace. *IEEE Personal Communications,* 4 (5), pp.58-64.

Burrell, J. and Gay, G. K. (2001) Collectively Defining Context in a Mobile, Networked Computing Environment. *CHI '01 Extended Abstracts on Human Factors in Computing Systems.* Seattle, Washington, ACM Press.

Chen, Y. and Kamara, J. M. (2008) Using Mobile Computing for Construction Site Information Management. *Engineering, Construction and Architectural Management (ECAM),* 15 (1), pp.7 - 20.

Fathi, M. S., Anumba, C. J. and Carrillo, P. (2006) Context Awareness in Construction Management - Key Issues & Enabling Technologies, In: Dulaimi, M.(Ed.), *The Joint International Conference on Construction Culture, Innovation and Management (CCIM).* British University, 26-29 November, Dubai, UAE. pp.425-435.

Fathi, M. S., Anumba, C. J., Carrillo, P. and Aziz, Z. (2007) Construction Programme Management - Current Context, In: Garvin, M., Edum-Fotwe, F. & Chinowsky, P.(Eds.), *Proceedings of the 2007 ASCE/CIB Construction Research Congress.* Academic Event Planners, 6-8 May, Grand Bahama Island. pp.8.

Garzaa, J. M. d. l. and Howitt, I. (1998) Wireless Communication and Computing at The Construction Jobsite. *Automation in Construction,* 7 (4), pp.327-347.

Ghaoui, C. (2006) *Encyclopaedia of Human Computer Interaction*. Covent Garden, London: Idea Group Reference

Imielinski, T. and Viswanathan, S. (1994) Adaptive Wireless Information Systems, *Proceedings of Special Interest Group in Database Systems (SIGDBS).* Tokyo, Japan. pp.19-51.

Löfgren, A. (2007) Mobility In-site: Implementing Mobile Computing in a Construction Enterprise. *The Communications of the Association for Information Systems,* 20 (37), pp.1-12.

Lycett, M., Rassau, A. and Danson, J. (2004) Programme Management: A Critical Review. *International Journal of Project Management,* 22, pp.289-299.

Magdic, A., Rebolj, D., Cuš-Babic, N. and Radosavljevic, M. (2002) Mobile Computing in Construction, In: Agger, K.(Ed.), *Proceedings of International Council for Research and Innovation in Building and Construction (CIB W78 Conference).* 12 – 14 June 2002, In Agger K. (Ed.), 12 – 14 June 2002, Aarhus School of Architecture, Denmark. pp.1-8.

May, A., Mitchell, V., Bowden, S. and Thorpe, T. (2005) Opportunities and Challenges for Location Aware Computing in the Construction Industry, *Mobile HCI 2005.* ACM, 19-22 September 2005, Salzburg, Austria. pp.255-258.

Milosevic, D. Z. (2003) *Project Management ToolBox: Tools and Techniques for the Practicing Project Manager* New Jersey: John Wiley & Sons

Oloufa, A. A., Ikeda, M. and Oda, H. (2003) Situational Awareness of Construction Equipment Using GPS, Wireless and Web Technologies. *Automation in Construction,* 12 (6), pp.737-748.

Pagonis, J. and Dixon, J. (2004) *Location Awareness and Location Based Services - Part 1 Positioning and Terminology.* [online] Symbian Ltd. Available from http://developer.symbian.com/main/downloads/papers/messaging/LocalAwareness_LBS_01.pdf [Accessed 18 August 2008]

Pashtan, A. (2005) *Mobile Web Services*. Cambridge: Cambridge University Press

Pellegrinelli, S. (1997) Programme Management: Organising Project-Based Change. *International Journal of Project Management,* 15 (3), pp.141-149.

Pellegrinelli, S. (2002) Shaping context: the role and challenge for programmes. *International Journal of Project Management,* 20 (3), pp.229-233.

Pernici, B. (2006) *Mobile Information System: Infrastructure and Design for Adaptivity and Flexibility*. Heidelberg, Germany: Springer

Schilit, B. N., Hilbert, D. M. and Trevor, J. (2002) Context-Aware Communication. *IEEE Wireless Communications,* 9 (5), pp.46-54.

Singhvi, V., Fish, W. and Terk, M. (2003) Context-Aware Information System for Construction Site Applications, In: Molenaar, K. R. & Chinowsky, P. S.(Eds.), *Proceedings of the Construction Research Congress.* ASCE, 19-21 March, Honolulu, Hawaii, USA. pp.115-115.

Smailagic, A., Siewiorek, D. P., Anhalt, J., Kogan, D. and Wang, Y. (2001) Location Sensing and Privacy In a Context-Aware Computing Environment *IEEE Wireless Communications* 9(5), pp.10-17.

Šuman, N. and Pšunder, M. (2008) Mobile Computing Changing the Traditional Ways of Organizing the Construction Company. *American Journal of Applied Sciences,* 5 (1), pp.42-47.

Tanaka, H. (2005) *Multi Project Management (MPM) at Project-based Companies.* [online] PM Forum Available from http://www.pmforum.org/library/papers/2005/Multi_Project_Management_Hiroshi_Tanaka.pdf [Accessed 23 April 2009]

Thurnher, B., Grill, T., Hummel, K. A. and Weigl, R. (2006) Exploiting Context-Awareness for Usability Evaluation in Mobile HCI, In: Kempter, G. & Hellberg, P. v.(Eds.), *Proceedings of Usability Day IV.* Pabst Science Publisher, 9 June, Vorarlberg, Dornbirn, Austria. pp.109-113.

Voelker, G. M. and Bershad, B. N. (1994) Mobisaic: An Information System for a Mobile Wireless Computing Environment, In: Cabrera, L.-F. & Satyanarayanan, M.(Eds.), *First Workshop on Mobile Computing Systems and Applications.* IEEE Computer Society, 8-9 December, Santa Cruz, California. pp.185-191.

Want, R., Hopper, A., Falcão, V. and Gibbons, J. (1992) The Active Badge Location System. *ACM Transactions on Information Systems,* 10 (1), pp.91-102.

Zreik, K. and Parfouru, S. (2005) A Context Driven Information Retrieval for Online Urban Disaster Management System, In: Sariyildiz, S. & Tuncer, B.(Eds.), *The 3rd International Conference on Innovation in Architecture Engineering and Construction (AEC 2005).* Delft University of Technology, 15-17 June, Rotterdam, The Netherlands. pp.1-11.