TOWARDS NEXT-GENERATION FACILITIES MANAGEMENT SYSTEMS

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ABSTRACT

There has been a tremendous growth in facilities management (FM) systems over the last twenty years. These systems have evolved from paper-based methods to become more IT-based. However, there are still limitations in the level of communication between different subsystems of an FM system and between the helpdesk and building management systems.

There are also inadequate links between computer-aided facilities management systems (CAFM) and decision analysis tools. Recent developments in information and communications technologies will enable these shortcomings of conventional systems to be addressed while opening up the possibilities for the development of next-generation FM systems. Such next-generation systems are expected to incorporate sensors, wireless communications systems, tagging and tracking systems (such as RFID), and advanced integrated software systems.

This paper explores this potential for the development of next-generation FM systems. It starts with a critical review of existing FM systems, and explores the enabling technologies for the next generation of FM systems. It then presents a scenario for the deployment of these systems and concludes with their potential benefits.

KEYWORDS

facilities management, information technology, sensor networks, wireless communications, RFID.

INTRODUCTION

Facilities Management (FM) has been defined variously in line with the development of the discipline, and is generally seen as the process through which an organization plans, manages, controls and delivers services to support and enhance business performance (US Library of Congress, 1989; Becker, 1990; Alexander, 1996; Varcoe, 2000; BIFM, 2001; IFMA, 2003). FM is believed to have its roots in the 1960's USA with the growing practice of banks outsourcing the processing of credit card transactions (Lord et al. 2002). In the UK, it evolved from a 'traditional' technical discipline with a focus on building services

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management to a management discipline focusing on providing non-core business support services. The next stage of its evolution is the creation and management of an 'experience'[4], as it moves out of a commercial setting to community-based settings.

In parallel with the evolution of FM, many developments have occurred in Information and Communications Technologies (ICT), some of which have been adopted in FM resulting in what is loosely referred to as Computer Aided Facilities Management (CAFM) systems. CAFM supports different aspects of operational FM including design (Sha and Chen, 2001; Udosen, 2003; Gopalakrishnan et al. 2004), maintenance (Teicholz, 1995), information management (Marsh and Finch, 1998; Keller and Keller, 2004), logistics and people management (Thompson, 2005). Various opportunities have also been identified for CAFM in process management (Hinks, 1998), 'intelligent delivery' (Finch, 2000), 'FM automation' (Lunn and Stephenson, 2000), asset management (Gabriel, 2003), and performance and risk management (Shohet and Lavy, 2004).

Although many developments have occurred in CAFM, they are mostly limited to the operational field. Lunn and Stephenson (2000) suggest that 'the increased proliferation of IT in facilities management has changed the profile of data importance'. They refer to CAFM systems as advanced controls which aid facility visibility through: automated helpdesks, embedded microchips within assets, advanced asset control technology (AACT), and total asset and people visibility systems (TAV).

Computerised helpdesks and building management systems are very popular, and wireless technologies are increasingly being introduced in the Facilities Management sector (McAndrew et al. 2005). For example, the CAFM Explorer has recently been released with added Blackberry capabilities (FMx Limited, 2005). These, however, tend to be standalone systems and do not feed into any strategic facilities management tools.

FM is usually broken down into strategic, tactical and operational functions (Then and Aklaghi, 1992). The strategic function has responsibility for developing vision, mission, plans and policy at high level. The tactical function concentrates on how the plans are to be implemented through the organisational structure and procurement policy, whilst the operational function is responsible for service delivery and quality control. Other authors have described the same functions in various ways including sponsorship, intelligence and service management (Williams and Roberts, 2000) and translator, processor and demonstrator (CFM, 2002). All of the CAFM systems reviewed in literature support operational or service management functions, demonstrating that apart from a lack of systems to support higher level functions in FM, there exist no capabilities within these systems to enable adaptation or integration into systems to support higher level FM functions (Hinks, 1998).

This paper explores the opportunities created by enabling technologies to support all three levels of FM functions. It starts with a brief critical review of existing CAFM systems. The enabling technologies that will influence the development of next generation FM systems are then described. This is followed by a scenario for the deployment of next

[4] FM is being seen more in terms of how to support businesses in relation to Pine and Gilmore's (1999) experience economy

generation FM systems while the concluding part of the paper outlines potential benefits of these systems.

CRITICAL REVIEW OF EXISTING CAFM SYSTEMS

Wikipedia (2006) defined CAFM as "the support of facilities management by information technology", where "supply of information about the facilities is the center of attention". Aperture (2006) describes CAFM as having evolved in the late 1980's automating the collection and maintenance of FM information, and providing the facility manager with the tools to track and report on facilities information such as: floor plans, building and property information, space characteristics and usage, employee and occupancy data, workplace assets (furniture and equipment), business continuity and safety information, and LAN (local area network) and telecom information. They go further to suggest that whilst CAFM systems have delivered some real benefits, and the industry has witnessed a growth in the use of such systems, their value has been limited by their inability to distribute information to those outside FM. This supports other literature that suggests limited and operational uses of CAFM systems.

A brief survey[5] of CAFM systems available on the market showed support for a wide range of operational and some tactical FM functions such as: helpdesk management, room bookings (which may be standalone or lined to the helpdesk or space management systems), space planning and management, moves management, space utilization and people tracking, asset management, planned and preventative maintenance, electronic document management, condition surveys, contract management, purchasing, stores/inventory control, project management, and cost control and financial tracking. Aperture (2006) sees the next step in the evolution of CAFM systems as the ability to "effectively and efficiently communicate the information stored in CAFM systems to the rest of the enterprise". Some systems claim to have this capability but there was little evidence available of its utilization.

Evidence in general has been difficult to collate, with very little recent research available in the public domain. Existing research, however, outlines some quantifiable and intangible benefits of CAFM systems (Lunn and Stephenson, 2000) – see Table 1.

Table 1: Tangible and Intangible Benefits of CAFM Systems

Tangible Benefits	Intangible Benefits
• reduced operational, occupational and maintenance costs; • people and asset visibility; • reduced space requests, churn and relocation; • better financial control and accountability; • improved contract management; • reduced duplication of effort and less mistakes.	• improved information quality and reliability; • better decision support; • fast reaction to change & business needs; • improved FM control; • identification of trends, 'What if?' • analysis and strategy prediction; • promotion of benchmark philosophy; • promoting survival on the edge of self-organising criticality; • helping to create and sustain a tactical and strategic competitive advantage.

[5] An internet search of companies which provided CAFM systems

ENABLING TECHNOLOGIES

There are numerous emerging technologies that will be important in the development of next-generation facilities management systems. A subset of these, which are of particular relevance, will be discussed here: Wireless Communication Systems, Web Services, Agent Technologies, Context-Aware Computing, Wireless Sensor Networks and Tagging Technologies.

WIRELESS COMMUNICATION TECHNOLOGIES

There have been significant advances in wireless networks in terms of protocols, standards, technology, quality of service and user acceptance over the last ten years. A wide range of portable devices, such as PDAs, mobile phones and other wearable devices are emerging, supporting W-WAN (wireless wide area networking), W-LAN (wireless local area networking) and PAN (personal area networking) capabilities. With the emergence of high speed wireless data transmission technologies (e.g. Bluetooth, W-LAN, 3G, GPRS), incorporating broadband and multi-media support, the opportunities for the delivery of FM data to distributed field workers is increasing exponentially.

Many recent research projects have focused on the application of mobile communication technologies in the construction sector. Some of these are discussed here. Ward et al (2004) implemented a Wireless Local Area Networking (W-LAN)- based system for wireless data collection on the construction site. Kuladinithi (2004) demonstrated the potential of mobile ad hoc communications within the construction industry while Rebolj et al (2001) conducted an experiment in which different aspects of mobile computing were tested on a construction site. 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 transmitting the information wirelessly on demand against the cost of transmitting it. The potential of using hand-held computers connected to a GPS receiver to support fieldwork was explored by Morse et al (1998). 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). McAndrew et al (2005) have developed 'Wireless FM' – a wireless Web-based system for the FM based on the ASP (Application Service Provider) model. The aforementioned research projects have demonstrated the potential of mobile communication technologies to support mobile and field workers, as in the FM sector.

WEB SERVICES

Web Services are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web. 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. 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. Thus, Web Services allow for low cost integration, by adherence to various common standards (Dahlem et al. 2002). A typical Web Services architecture consists of three entities (Figure 1): service providers, service users and service brokers (or service registries).

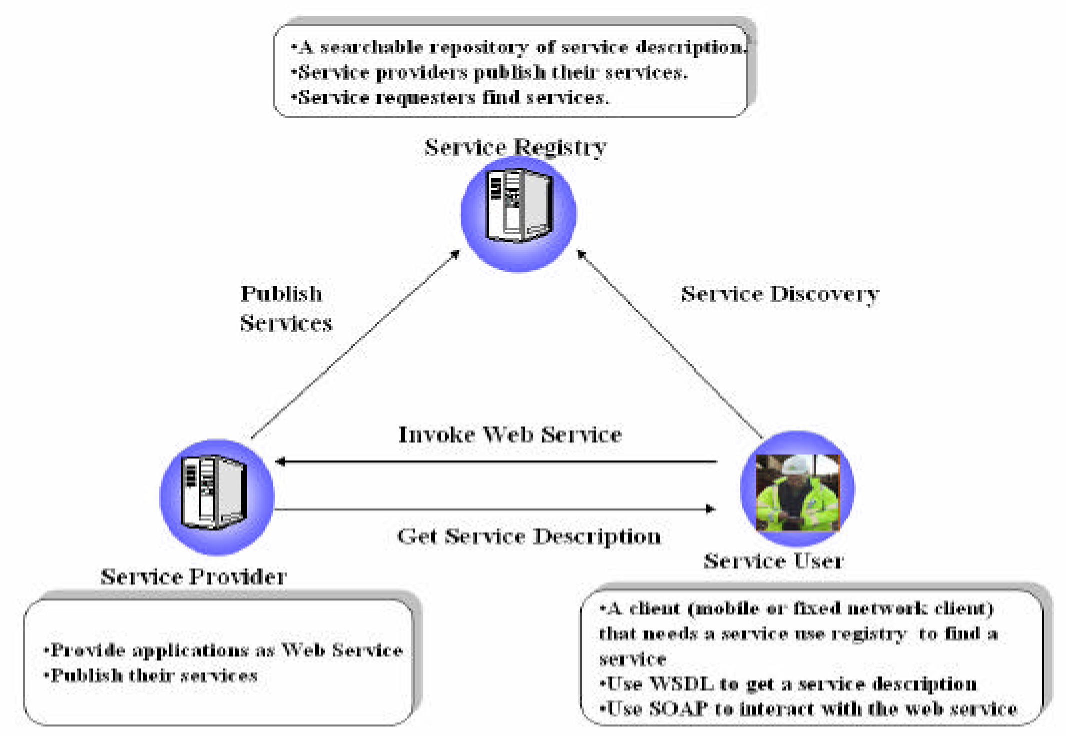

Figure 1: Three Entities of Web Services Architecture

- ***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 the Universal Discovery and Description Interface (UDDI).
- ***Service Providers*** publish their services through brokers who maintain registries that clients can look up.
- ***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.

Packaging construction and FM software applications as Web Services can potentially remove the barriers of geographic boundaries and expedite construction project delivery (Cheng et al. 2003). The feature of loose coupling can play a key role in integrating disparate systems to FM systems, since applications are constantly evolving. Web Services provide a flexible way of discovering and integrating emerging applications. The technology can play a key role in the realisation of next generation FM Systems by enabling facilities managers to procure products and services on the Web.

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 & Jennings, 1995). In many systems, several agents are required to work in concert, resulting in a multi-agent system (MAS). 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. Ren and Anumba (2004) and Anumba et al (2005) have reviewed the development and applications of MAS in construction. 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, telematics and computer supported cooperative work. Agent technologies can be used in concert with the other technologies described here to provide intelligent, context-specific support to facility managers and their staff.

CONTEXT-AWARE COMPUTING

Context-aware computing is defined by Burrell and Gay (2001) as the use of 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. The application of context awareness for mobile workers has been demonstrated in a large number of applications, including fieldwork, museums, route planning, libraries and tourism. Other projects that have specifically focused on location-based data delivery include the GUIDE project (Davies et al. 1999) and the Mobile Shadow Project, MSP (Kortuem et al. 1999). The MSP approach is based on the use of agents, to map the physical context to the virtual context. Context-aware applications are also being investigated by other fields of research in computer science, including mobile computing, wearable computing, augmented reality, ubiquitous computing and human computer interaction. However, the application of context-aware technologies in the construction industry remains limited. Context-aware computing can play an important role in the realisation of next generation FM systems by allowing applications to better understand the user's context and adapting services to the interpreted context, thereby ensuring that the user gets highly specific data and services.

WIRELESS SENSOR NETWORKS AND TAGGING TECHNOLOGIES

Wireless sensors are small devices which are capable of performing a sensing task [Park et al. 2000]. There are different categories of sensors, such as fibre-optic, photoelectric, radio-frequency identification, chemical, and acoustic. A wireless sensor network is a network of such devices capable of a cooperated sensing task. There is growing interest in the construction industry in this relatively new technology. Recent advances in wireless sensor networking technology 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). They promise a much wider range of applications in the construction industry and 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, environmental monitoring, site security, automated tracking of expensive materials on site, safety management and many others (Aziz et al. 2002).

Tagging technologies are also becoming of interest to facility managers. The most popular type is the Radio-Frequency Identification (RFID) tag - a specific category of wireless sensors. RFID tags are used mainly for asset tracking but can also be used for the provision of maintenance information. Wi-Fi tags can be used instead of RFID tags and rely on a wireless LAN. They can be used for monitoring purposes, collecting and transmitting data to a central station – this could be the facility management group's main computer – and for asset or personnel tracking. The advantage of this technology is that it does not require a complex infrastructure in comparison to RFID. A Wi-Fi Positioning Engine can be used to track the real-time location of tagged items (assets or personnel).

SCENARIO FOR DEPLOYMENT OF NEXT GENERATION FM SYSTEMS

To illustrate the synergy between various technologies discussed earlier, a future deployment scenario is presented. The scenario is presented as a day in the life of an electrical technician, John, who works in the facilities management department of a university. His role involves maintaining HVAC (heating, ventilation and air-conditioning) systems across the campus and servicing different work order tickets, which arise from time to time. The key elements of the scenario are illustrated in Figure 2 and are discussed below:

1. As John arrives for work, the on-campus wireless network detects his presence (via IP address of his smart-phone) and prompts him to log-in. After a successful log-in, details are captured for payroll and health and safety objectives and a list of services including a daily task list is pushed on to his device. The workflow management system dynamically allocates tasks to technicians based on various context parameters such as their location, work-load, work schedule and expertise. John refers to his task list frequently, as the priority of various tasks change from time to time. He records the completion of tasks from his point of work; this is recorded in real-time.
2. Today the first task in his list is to respond to an early call by a staff member about a meeting room in the Civil Engineering building which was reported to be 'too stuffy'. Using his Bluetooth earpiece, he connects to the Building Automation System and uses voice command to request a HVAC status check. The system responds with a reported temperature of 31 degrees centigrade and a humidity level of 65%. A remote status check also reveals that both heating and humidity levels are continuously increasing.
3. For a more detailed inspection, John goes to the warehouse to get his HVAC inspection kit. Using his smart-phone, he is guided to the location of the kit. All expensive items in the warehouse are tagged using RFID, in order to maintain an audit trail of tools (by recording who last had charge of a particular item) and ensure security (e.g. alerts are

generated if an expensive item is removed from the premises without permission). Throughout the campus, key assets are tagged, and the tagged information is used to create virtual reality displays using real time location and status tracking. This allows for remote monitoring of different assets. Every time the location of an expensive item changes without prior approval, an appropriate alert is generated.

4. After picking up the kit, John returns to the room in the Civil Engineering building. He uses the Bluetooth enabled kit to test the thermostat and discovers a humidity related problem. He also gets a pop-up message on his device (sent by the knowledge management server) indicating that a similar problem was reported last year and a specialist HVAC contractor was called in. As the heating in the room needs to be fixed as a priority, John, decides to call the specialist HVAC contractor, whose current status is set to 'available'. John initiates a video call sending a streaming video. The remote expert runs a remote check through his handheld communication device and diagnose that a particular valve needs replacement.
5. As the replacement valve is not stocked, John uses his smart phone to search for approved suppliers that can provide the valve. The FM Department's procurement agent obtains the information about the component suppliers using a popular electronic market registry, which contains a list of approved suppliers. The trading registry is based on the Web Services standards, which allows the suppliers to map the data about their products and services into a standarised format, clearly defining the meanings of the terms used in the market place and the rules of data exchange. A list of potential suppliers is then passed from the procurement agent to a personalisation agent, which renders the information on the workers' device, in line with user preferences (e.g. language, device type, location, level of detail etc). In this situation, 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 the corporate procurement application and suppliers through a shared ontology. Suppliers respond individually by sending their quotes. John evaluates the bids from the suppliers, and the best quote is then selected and a purchase order is generated. The procurement agent and the selected supplier's agent negotiate using a shared ontology, and agree on payment for the products and other contractual details. The underlying semantics ensure intelligent inter-agent communication/negotiation. An order confirmation is sent back to the buyer, with delivery information. A monitoring agent will monitor the order, ensuring products are delivered by the right date. Any discrepancies are notified to the project manager.

The above scenario will result in automatic capture of much of the operational data and information relating to FM tasks in such a way that they can inform both tactical and strategic decisions. For example, the storage of previous case histories on the knowledge management server will enable managers to undertake longitudinal planning, as well as keep track of the performance of specialist contractors. Managers can also monitor the performance of maintenance personnel over a period of time. Strategic issues relating to long-term approaches to the management of the university facilities can then be addressed based on a sound knowledge base.

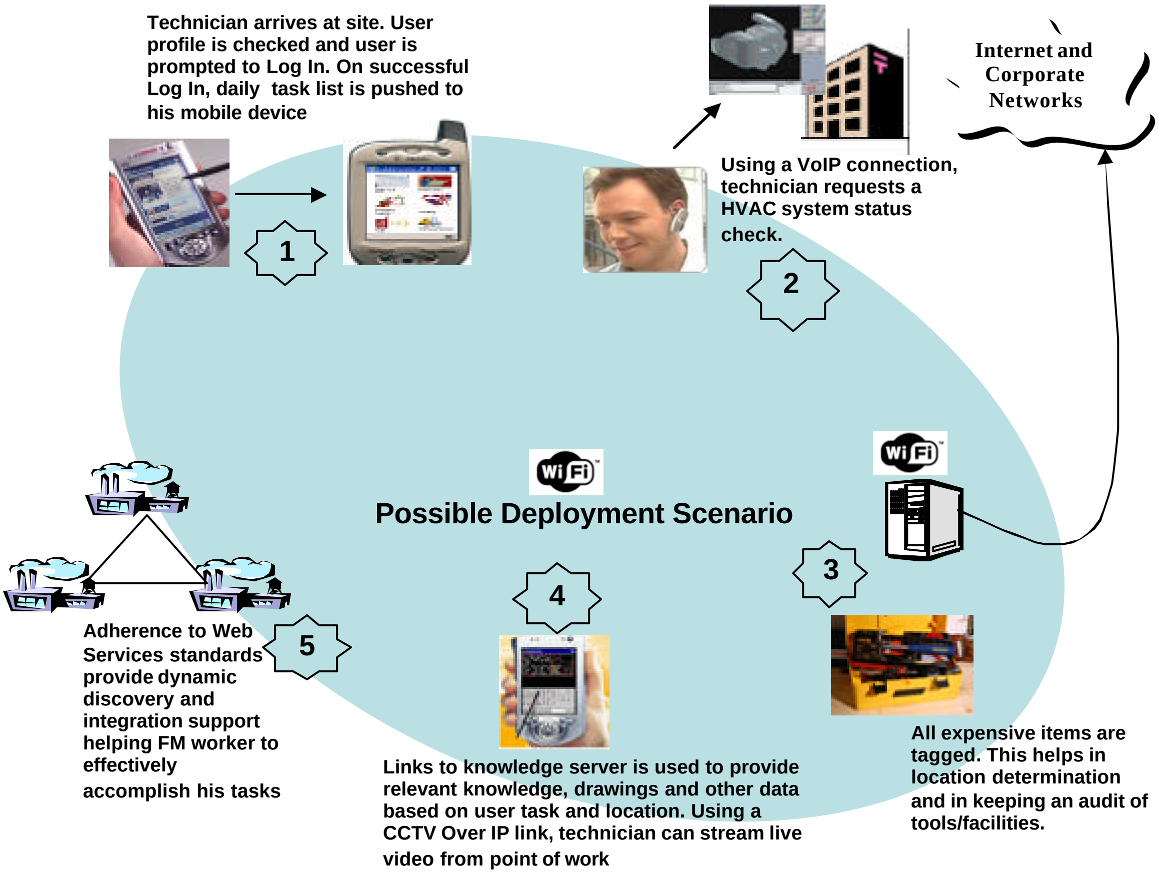

Figure 2: Possible Deployment Scenario

SUMMARY AND CONCLUSIONS

This paper has explored the potential for the development of next-generation FM systems based on emerging information and communications technologies. The limitations of existing computer-aided facilities management systems were outlined and the enabling technologies for next generation FM systems briefly described. A scenario is used to illustrate the integration of these technologies in facilities management. Such next generation FM systems can offer considerable benefits. A few of these are listed below:

- Facilities managers can track the location and status of key assets at any time;
- Maintenance workers can have information and services specific to their current role and task pushed to their PDAs;
- The co-ordination of FM field workers can be significantly enhanced with the facilities manager able to monitor the completion of tasks in real time, re-order priorities, and re-assign tasks to workers;
- The procurement of specialist goods and services can be automated and speeded up;

- There is scope for improved real-time data capture from facilities using wireless sensor networks – this can ensure that critical items are replaced in good time.
- Facilities managers can automatically collect data and information from the operational level, which can inform tactical and strategic decision making – a key limitation of existing FM systems.

Clearly, much work needs to be done before the vision of next-generation facilities management systems outlined here is realised. The enabling technologies already exist and need to be harnessed. The development and practical deployment of FM systems with the functionality alluded to in the scenario presented in the paper will unearth organisational and human factors issues that will also need to be addressed before the full benefits of these systems can be realised.

REFERENCES

Akyildiz, I. F., Cayirci, E., Sankarasubramaniam, Y. & Su, W. (2002). 'Wireless Sensor Networks: a Survey'. *Computer Networks*, 38 (4) 393-422.

Alexander, K. (1996). Value Management. In Alexander, K. (editor)(1996). *Facilities Management - Theory and Practice*. E & FN Spon, New York, NY.

Anumba, C. J., Ugwu, O. O. & Ren, Z. (2005). Agents and Multi-Agent Systems in Construction. Taylor & Francis Books Ltd, London.

Aperture (2006). *Enterprise Strategy: The Evolution of CAFM*. (available at http://www.aperture.com/facilities/evolution_of_cafm.php)

Aziz, Z., Tah, J. H. M. & Carr, V. (2002). 'Wireless Sensor Network Applications for the Construction Site'. *Proceedings eSM@ART and CISEMIC Conferences*, University of Salford, 18-21 November, 24-34.

Becker, F. (1990). *The Total Workplace: Facilities Management and the Elastic Organisation*. Van Nostrard Reinho ld, New York.

British Institute of Facilities Management. (2001). *Facilities Introduction*. (available at http://www.bifm.org.uk) September.

Burrell, J & Gay, G. K. (2001). 'Collectively Defining Context in a Mobile, Networked Computing Environment'. *Short Talk Summary in CHI 2001 Extended Abstracts*, May.

Centre for Facilities Management. (2002). *World Class FM – Case Study Report*. Confidential Commissioned Report published by the Centre for Facilities Management, Salford University, September.

Cheng, J., Law, K. & Kumar, B. (2003). 'Integrating Project Management Applications as Web Services'. *Innovative Developments in Architecture Engineering and Construction,* Anumba C. J. (editor), Millpress Science Publishers, June, 367-376.

Dahlem, D., Jahnke, J. H., Onabanjo, A. & Wang, O. (2002). 'The Challenges of Implementing Web Services on Small Devices'. *Proceedings Workshop on Pervasive Computing - Going Beyond Internet for Small Screens*, OOPSLA 2002, Washington, USA, November 4th.

Davies, N., Cheverst, K., Mitchell, K. & Friday, A. (1999). 'Caches in the Air: Disseminating Information in the Guide System'. *Proceedings of 2nd IEEE Workshop on*

Mobile Computing Systems and Applications (WMCSA'99), IEEE Press, Louisiana, USA, February, 11-19.

Fensel, D. (2001). *Ontologies: Silver Bullet for Knowledge Management and Electronic-Commerce* Springer-Verlag, Berlin.

Finch, E. (2000). 'Third-wave Internet in Facilities Management'. *Facilities*, 18 (5-6), 204-212.

FMx Limited (2005). New Blackberry-friendly CAFM Explorer is the Pick of the FM Software Market. (available at http://www.cafmexplorer.com/blackberry-fm.php).

Gabriel, G. C. (2003). 'Decentralizing Asset Management in a University Environment'. *Facilities*, 21 (10), 233-243.

Gopalakrishnan, B., Turuvekere, R. & Gupta, D. P. (2004). 'Computer Integrated Facilities Planning and Design'. *Facilities*, 22 (7-8), 199-209.

Garza, I. M. & Howitt, I. (1998). 'Wireless Communication and Computing at the Construction Site'. *Automation in Construction*, 7 (4), 327-347.

Hinks, J. (1998). 'A Conceptual Model for the Interrelationship between Information Technology and Facilities Management Process Capability'. *Facilities*, 16 (9-10), 233–245.

IFMA (2003). *Occupational Definition of Facility Management*. (available at http://www.ifma.org/whatsfm/occ_definition.cfm?actionbig=9&actionlil=173)

Keller, J. M. & Keller, C. (2004). 'Bringing Strategic Efficacy to Facility Management Through CAFM Tools'. *Journal of Facilities Management*, 3 (2), 125-144.

Kortuem, G., Bauer, M. & Segall, Z. (1999). 'NETMAN: the Design of a Collaborative Wearable Computer System'. *Mobile Networks and Applications (MONET)*, 4 (1), 49-58.

Kuladinithi, K., Timm-Giel, A. & Görg, C. (2004): 'Mobile Ad-hoc Communications in AEC Industry. *ITcon*, 9, 313-323, (available at http://www.itcon.org/2004/22).

Lord, A., Lunn, S., Price, I. and Stephenson, P. (2002). *Emergent Behaviour in a New Market: Facilities Management in the UK*. (available at http://www.shu.ac.uk/fmgc/).

Lunn, S. D. & Stephenson, P. (2000). 'The Impact of Tactical and Strategic FM Automation'. *Facilities*, 18 (7-8), 312-322.

Marsh, L. & Finch, E. (1998). 'Using Portable Data Files in Facilities Management'. *Facilities*, 16 (1-2), 21–28.

McAndrew, S. T., Anumba, C. J., Hassan, T. M. & Duke, A. K. (2005). 'Potential Use of Real-Time Data Capture and Job Tracking Technology in the Field'. *Facilities*, 23 (1-2), 31-46.

Meissner, A., Baxevanaki, L., Mathes, I., Branki, C., Bozios, T., Schonfeld, W., Crowe, M. & Steinmetz, R. (2001): 'Integrated Mobile Operations Support for the Construction Industry: The COSMOS Solution'. *Proceedings 5th World Multi-Conference on Systemics, Cybernetics and Informatics*, SCI 2001, Int. Institute of Informatics and Systemics, July, Orlando, USA, IV/248-255.

Morse, D., Pascoe, J., Ryan, N., Birkett, A. & Pinkney, K. (1998): 'Will the Computer Ever Replace the Field Notebook?' *British Ecological Society*, Winter Meeting, 1998.

Park, S., Savvides, A. & Srivastava, M. B. (2000). SensorSim: A Simulation Framework for Sensor Networks. Electrical Engineering Department, University of California, LA, *Proceedings of MSWiM 2000, Boston, August 11* (available at http://nesl.ee.ucla.edu/projects/sensorsim/papers/sensorsim.pdf)

Pine II, B.J. and Gilmore, J.H. (1999). *The Experience Economy.* Harvard Business School Press, Boston, Massachusetts.

Rebolj, D., Magide, A. & Babie, N. (2001): 'Mobile Computing in Construction', Advances in Concurrent Engineering. *Proceedings 8th ISPE International Conference on Concurrent Engineering, Research and Applications*, California, USA, July 28-August 1.

Ren, Z & Anumba, C. J. (2004): 'Multi-agent Systems in Construction – State of the Art and Prospects'. *Automation in Construction,* 13, 421– 434

Sha, D. Y. & Chen, C. (2001). 'A New Approach to the Multiple Objective Facility Layout Problem'. *Integrated Manufacturing Systems*, 12 (1), 59-66.

Shohet, I. M. & Lavy, S. (2004). 'Healthcare Facilities Management: State of the Art Review'. *Facilities*, 22 (7-8), 210-220.

Teicholz, E. (1995). 'Computer-Aided Facilities Management and Facility Conditions Assessment Software'. *Facilities*, 13 (6), 16–19.

Then, D. S. S. & Akhlaghi, F. (1992). 'A Framework for Defining Facilities Management Education'. *Facilities Management – Research Directions,* Barrett, P. (editor), Surveyors Holdings Limited, London.

Thompson, B. (2005). 'Information and Communications Technology and Industrial Property'. *Journal of Property Investment & Finance*, 23 (6), 506-515.

Udosen, U. J. (2003). 'Computerized Workplace Design Using CADWORK Heuristics'. *Work Study*, 52 (7), 358-363.

US Library of Congress. (1989). In Mole, T. and Taylor, F. (1992). Facility Management: Evolution or Revolution. In Barrett, P. (editor) *Facilities Management – Research Directions*. Surveyors Holdings Limited, London.

Varcoe, B. (2000). Implications for facility management of the changing business climate. *Facilities*, 18(10/11/12), 383-391.

Ward, M., Thorpe, A., Price, A. & Wren, C. (2004): 'Implementation and Control of Wireless Data Collection on Construction Sites'. *ITcon*, 9, Special Issue Mobile Computing in Construction, 297-311, (available at http://www.itcon.org/2004/21)

Wikipedia (2006). CAFM. (available at http://en.wikipedia.org/wiki/CAFM).

Williams, B. & Roberts, P. (2000). 'The Developing Role of the Intelligent Client'. *World Workplace: The Evolution of Thought on the Modern Workplace,* Proceedings of the EuroFM/IFMA Facilities Management Conference and Exhibition, in partnership with BIFM and CFM, Glasgow, Scotland. 11-13 June. 239-242.

Wooldridge, M. & Jennings, N. R. (1995): 'Intelligent Agents: Theory and Practice'. *The Knowledge Engineering Review*, 10 (2), 115-152.