Context-Sensitive Maintenance Management using Mobile Tools

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ABSTRACT

To address the essential elements of building maintenance, the use of mobile technology to assist in the decision making processes of Facility Management (FM) is rarely exploited. The operation and maintenance (O&M) phase of a building life-cycle (BLC), which research has found accounts for between 50-70% of professional involvement over the BLC, is the main focus of the research. One of the key aims of this phase of a BLC is the optimisation of energy consumption and this is achieved through careful monitoring of performance levels and effective maintenance of building services. Research estimates that energy savings of between 15-40% can be achieved through closer monitoring and supervision of energy use. This paper introduces the research of the ITOBO project and how to achieve improved building operation through the integration of Data Warehousing technology to provide an Information Technology platform for building performance monitoring and maintenance. A context sensitive mobile application was developed to provide FM personnel access to building maintenance data of UCC's Environmental Research Institute building.

Keywords: Building maintenance; Context awareness; Data Warehousing; Mobile devices; Web services

1.0 INTRODUCTION

Increased energy efficiency is at the heart of the Irish governments agenda over the next ten years. The Minister for Communications, Energy and Natural Resources, Eamon Ryan, has outlined in DOTT (2008) the two major energy challenges facing Ireland as being:

(i) Securing the supply of reliable and affordable energy, and
(ii) Achieving the transformation to a low-carbon, high-efficiency, sustainable and smart energy system.

In order to achieve these objectives, the use of advanced Information and Communication Technologies (ICT) will play a vital role. These technologies will support both maintenance engineers and facilities managers in their activities to identify and analyse performance criteria from buildings mechanical and electrical (M&E) plant. Consequently, mobile technologies are going to provide a considerable contribution in managing maintenance processes and reducing energy consumption. Tolman *et al.* (2009) stated that by using mobile technology, a more intuitive decision making process for maintenance can be achieved.

In Emmanouilidis *et al.* (2009), mobile technology can have a positive impact by removing obstructions related to location and temporal constraints, this enables the development of intelligent software applications to present context sensitive information to different types of stakeholders in FM on plant O&M decision making and processes. This can enable remote access to building data through concise communication channels with everyday devices like mobile phones over the Web.

O'Sullivan *et al.* (2004) outlined that energy savings of between 15-40% could be made in buildings by closer monitoring and supervision of energy use. In order to reach these targets, greater emphasis must be placed on analysing building performance, that enhance owner, operator and occupant interests in such areas as energy, lighting, thermal comfort and maintenance.

FM is broken into three specific areas; technical, infrastructural and commercial (Barrett and Baldry, 2003). This paper is strongly focused in the area of technical facilities management and this area is centered on the operation and maintenance of a buildings mechanical and electrical (M&E) systems. It focuses on energy management and costs associated to energy consumption and maintenance of M&E services such as HVAC (Heating, Ventilation, Air-Conditioning), lighting, CO2 control, and humidity.

In terms of maintenance, the facility manager will generally consider requisites such as accountability, efficiency and accuracy (Capehart *et al.*, 2008). A facility manager must always acknowledge the primary processes that are associated with a particular building whether it is domestic, commercial or industrial. Therefore, the higher the importance of these processes the higher the level of service. Maintenance of most buildings will require the facilities manager to interact with key actors such as technical, legal and social personnel who govern that particular building. In order for these interactions to be successful it is important that the facility manager has clear and accurate knowledge of the financial provisions associated with maintenance of the building in question. Some of these provisions may include the number of times a component has been in trouble over a period of time, downtime, the reaction time of the facility manager and service teams, and the availability of the component.

Having identified to fundamental principles of managing building operations and maintenance the ITOBO project will be introduced in the next section to outline the technologies and framework to address current deficiencies in FM.

2.0 ITOBO Project

The findings of ITOBO (Information and Communication Technology for Sustainable and Optimised Building Operation) (2008) research cluster involves monitoring building performance through the use of Building Information Models (BIM) and the collection of data from Wireless Sensor Networks (WSN) (Menzel *et al.* 2008, Spinar *et al.* 2009) are used as a baseline for the FM solution.

ITOBO focuses on applying FM standards on building performance levels and delve into aspects of building control. Utilising data warehousing methodologies on the flow of data from both the existing Building Management System (BMS) and an additional WSN deployment, a basis is provided to extract relevant aggregated building performance data for a maintenance system.

In order to deploy the system, the Environmental Research Institute (ERI) Building which is owned by UCC (Kennett 2005, Croly 2003) is used as our living laboratory. The ERI building will be used to test and validate our results ERI is managed by a general manager and caters for multiple organisations with laboratory, office and meeting spaces available. A Cylon BMS was installed by McCool Controls using a wired backbone to connect to its sensors, meters and actuation nodes. Maintenance activities including inspection, calibration and replacement of faulty equipment are contracted to Sirus Engineering. The FM software used by B&E is a helpdesk application and they do not have a system for recording maintenance work orders for quality reviews and audits.

3.0 METHODOLOGY FOR CONTEXT-SENSITIVE MAINTENANCE

Mobile applications have been developed for a wide variety of domains to allow users easier access to complete tasks or provide access to information over wireless networks. This research aims to address core elements of mobile devices in order to provide FM stakeholders, like facility managers and maintenance engineers, access to building performance and maintenance data. Context Awareness is a methodology developed to address the critical factors required for software application on mobile devices.

An overview of the components involved in the maintenance management system is described in Figure 1. The foundation to any sensing system is a layer of sensors, meters and for control purposes actuators are deployed. Having collected data from the sensing layer, a data warehouse can support data from multiple data sources and be combined with a BIM describing the building structure and the sensing device properties. Once the data is processed, views can be generated to support the end users and support their maintenance process. These services are developed using Web services and are designed to support the context information sent to the mobile devices.

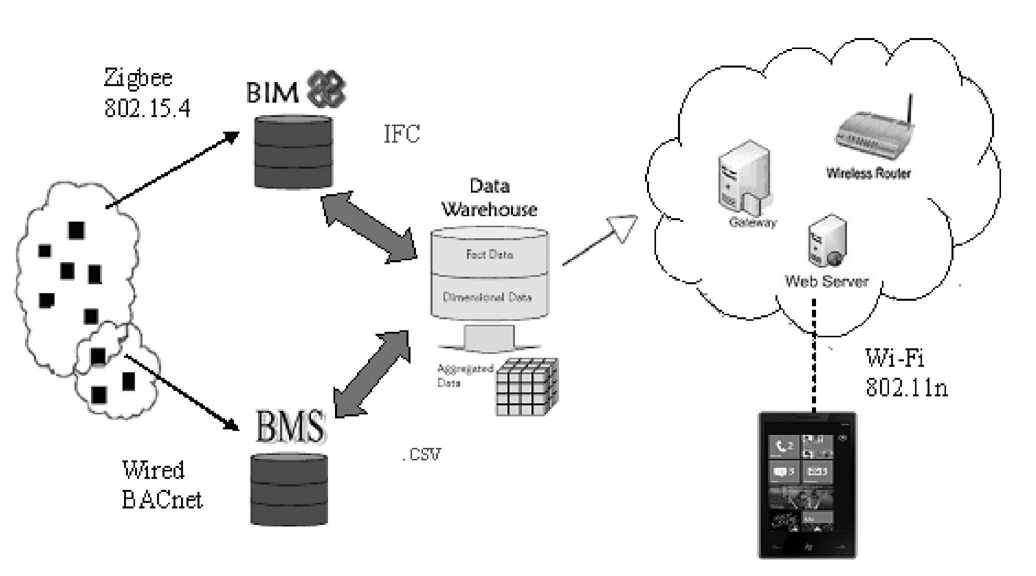


Figure 1: Maintenance Management System components

3.1 Context Awareness

Context Awareness was originally a term from ubiquitous or pervasive computing which allowed software applications on small, restricted device to link with changes in its environment. Context is defined as any information that can be used to characterise the situation of an entity (Dey, 2000). An entity could be a person, place or object relevant to the user and the application. Various categories of context have been defined to deal with user characteristics, location time and properties of the mobile devices. Contexts are developed in order to deal with optimal transmission of data to the device and in turn satisfy the end user requirements. The following sections address the core aspects in order to create a context sensitive maintenance management system.

3.1.2 Sensing Layer

Sensors are the source of data for monitoring building. Sensors and meters collect information from many elements of a building's HVAC system and can also be deployed to check electricity, gas and water consumption. BMS data is collected on a nightly basis from 205 sensing devices and these devices normally sense with a 15 minute sampling interval. Given that each device generates 96 data reading per day, millions of records of building performance data have been collected since 2007 up to the present day. Mobile devices and wireless networks will perform poorly if large amounts of data are transmitted and need to be processed.

3.1.3 Building Information Model

Having collected data from multiple sensing devices, this information needs to be linked to physical elements of the building(s) being maintained. One of the fundamental benefits of BIM is its ability to enhance interdisciplinary collaboration throughout the BLC from conception through to design, construction, operation, re-use and even demolition. It provides users with the ability to model and manage information on drawings, reports, design analysis, schedule simulation and facilities management so more informed decisions can be made. BIM stores all this information in a single data repository to provide transparency and reduce miscommunication between different parties involved in the project (Eastman *et al.*, 2008). Information can be extracted from a BIM using IFC and gbXML to support the maintenance processes.

3.1.4 Data Warehousing

Data warehouses are used from bringing together selected data from multiple sources and storing it in a single repository for later querying and analysis (Inmon, 1992). Figure 2 shows a data warehouse schema that was developed to enhance building performance monitoring and maintenance through collecting performance data from sensors and meters and storing it in relative tables. Relationships were developed to link the BIM data with the data that is collected.

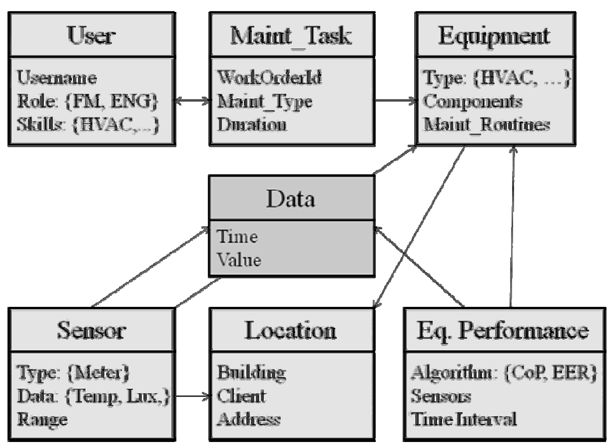


Figure 2: Simplified Data Warehouse tables to support maintenance processes

3.1.5 Web Services

Web services are used to accommodate web and component based systems in a single framework (Deitel *et al.*, 2003). This research investigates the use of Web services to support a Service Oriented Architecture for FM stakeholders by providing a set of services to access building performance and maintenance information from mobile devices as seen in Figure 3. These services were developed to support access to performance levels of building equipment over different time periods and over different time intervals. Also access to historical maintenance task information will assist in identifying fault causes and view equipment inspections and repairs.

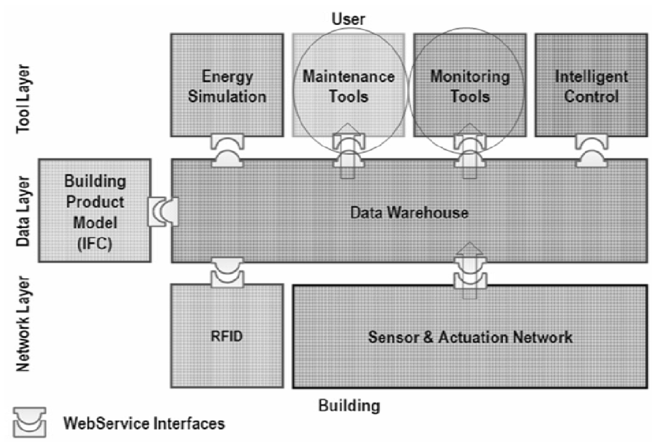


Figure 3: Overview of Maintenance Web services within the ITOBO software platform

3.1.6 Mobile Devices

The term mobile technology within the FM domain does not necessarily suggest that the device is constantly moving; alternatively the technologies used maybe fixed in a certain location on a certain component. Facility managers who are responsible for the maintenance of building plant specify certain requirements of the device. These requirements may include; their ability to access data contained within database and web servers at any time and location, ability to communicate with sensors attached to building plant, and their interoperability with wireless networks (Campos *et al.*, 2008). Key areas that need to addressed for mobile computing are limited battery power, wireless transmission of data, limited processing power, limited memory storage and restricted screen resolution and screen size.

4.0 MOBILE MAINTENANCE SYSTEM

After identifying the potential difficulties associated with developing a mobile maintenance application, this section outlines a prototype to overcome such difficulties using context sensitive fundamentals. The mobile device accesses information relating to equipment performance in order to optimise equipment operation.

The prototype application was developed using an iPhone as a testing device and using the Safari Web browser. The end user application is created with Google Web Toolkit which supports a wide range of Web browsers and alleviates most compatibility issues associated with Web development and also, incorporates Ajax framework for quick responsive end user Web applications. This application was hosted on a Glassfish Server which allows access over the web whereby any mobile device can access the information.

Currently the Data Warehouse has collected over 20 million records for the ERI building. In Figure 4 a view of the operations of renewable HVAC components to supply heat to the underfloor system is plotted over a week. The renewable energy sources of a solar panel circuit and a geothermal heat pump are compared to check for any deficiencies while supplying heat for consumption in the underfloor system. Each component has a meter to monitor individual system operating levels. So in order to access relevant data from the Data Warehouse, the user can select options in the application to select equipment performance data according to their current maintenance task, over a specified time interval and dates, and the necessary Web service is initiated to retrieve data from a preprocessed view. Therefore, eliminating traditional database runtime querying of all data records collected.

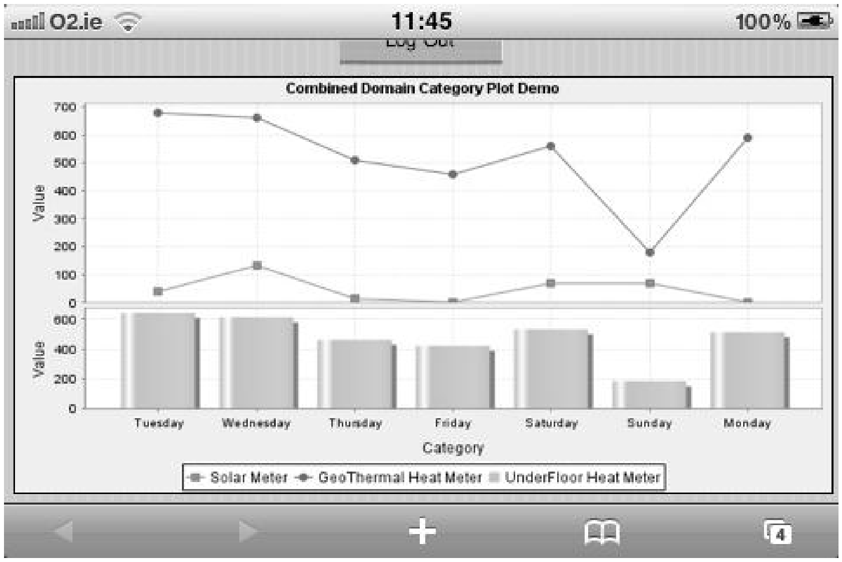
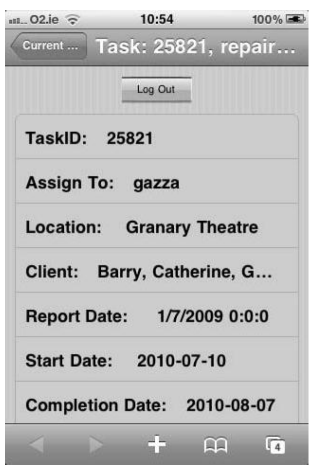


Figure 4: Simplified Data Warehouse tables to support maintenance processes

Figure 5 is a view that enables a facility manager or maintenance engineer to browse over details of previous maintenance tasks carried out in the location of the current task. Further information relevant to tasks is also portrayed in Figure 6. To address aspects of maintenance tasks, information is contextualised into small fragments of information so an intuitive navigation mechanism is required to enable quick and easy access to critical information.



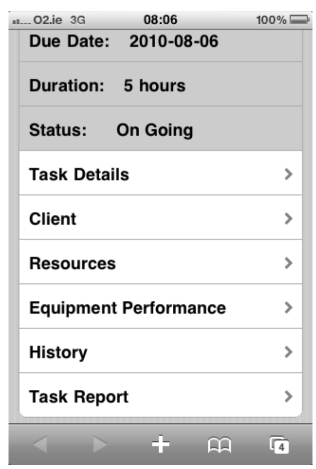


Figure 5: Mobile view of Equipment Maintenance Historical Record

Figure 6: Contextualised Mobile Device Menu for Maintenance Task

5.0 CONCLUSIONS

The research has focused on a context sensitive development methodology to support information communication that is required by a facility manager in order to achieve effective building performance monitoring and maintenance processes. It has proposed a solution to carry out performance monitoring in remote locations by using a mobile device which enables maintenance personnel to access geothermal heat pump performance in the ERI building.

The advantage of BIM tools is that it promotes interdisciplinary collaboration throughout the BLC and it provides real-time mapping of building components. The data warehouse is used to collect, store and transport building performance data upon request. The data stored within the data warehouse can be queried and accessed by a facility manager's mobile device by way of web services. The integration of these applications over common communication platforms will enhance BPM standards and allow the facility manager make more informed decisions for maintenance activities.

6.0 ACKNOWLEDGEMENTS

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Innovative Models for Procurement of Major Infrastructure Projects in Development

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ABSTRACT
Use of collaborative procurement based on target cost contracts is on the increase in construction worldwide. Other innovative arrangements for procurement include Early Contractor Involvement (ECI) design and build. In this paper, the key features and risk allocation inherent in target cost contracts are discussed. The characteristics of ECI contracts are assessed including an evaluation of the payment mechanisms in a major rail project. It is concluded that experience of ECI design and build contracts is still limited. As a consequence, further theoretical research and empirical data analysis are required to collate information which will guide industry in designing effective incentives in collaborative procurement for development projects.

Keywords: contracting, development, incentives, partnering, procurement, risk.

1.0 INTRODUCTION

In recent years, there have been major advances in collaborative procurement in construction worldwide. All project participants are increasingly working together in a variety of contractual arrangements including partnering, alliances, joint ventures and framework contracts. Building trust is a key ingredient in such arrangements. To achieve true collaboration, a legally binding contract that aligns the motivations of the parties is essential. Although lump sum and admeasure contracts are still widely used, the development of the NEC Engineering and Construction Contract (ECC) has led to widespread use of target cost contracts. Wright and Fergusson (2009) investigated use of the NEC ECC in New Zealand and found that the contract form delivers business benefits in terms of project management, contract clarity and contractual relationships. The contract provides a forward looking proactive environment in which to manage project cost and time although use of the target-sum payment option requires additional time and cost for administration. The authors conclude that the contract form provides the unexpected benefit of added occupational safety most probably due to better forward planning.

The theory of risk sharing and incentives in target cost contracts has been widely reported in the economics literature. This work adopts principally a mathematical modelling approach and specific assumptions regarding the contracting relationship between the client and the contractor. For example, a principal-agent analysis by Weitzman (1980) concludes that an optimal sharing ratio in target cost contracts depends on various factors. These factors include the level of project uncertainty, the degree of risk aversion by the parties and the contractor's ability to control costs. Another principal-agent analysis by McAfee and McMillan (1986) suggests that an optimal contract that minimises procurement costs is never a cost-plus contract. It may be a fixed-price contract but that such contracts should be used much less frequently. They conclude that an optimal contract is usually an incentive contract and that a client's choice of the sharing ratio determines the contractor's choice of cost-reducing activity. The larger the share of costs paid by the client, the smaller the effort expended to lower production costs.

In target cost contracts, the contractor is reimbursed all the allowable project costs. In addition, he is paid a fee to cover overhead expenses and profit. The contractor and the client will also normally share the difference between the target cost and the actual cost of the