

# Facilitating the link between point-of-production workers and corporate ICT systems in construction

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**ABSTRACT:** Web-based project management systems (WPMS) are becoming more widespread within construction and have shown to be beneficial in improving communications and document transfer between project participants. However, the challenge of integrating point-of-production workers into such systems still remains largely unrealised. This paper describes current applications within construction that are addressing these challenges. The technologies employed vary from tablet PC's, PDA's to RFID tags. The paper examines in detail a web-based data capture and management system for piling works, utilising a site-based web server and wireless network. The system effectively allows for the expansion of existing WPMS to include construction site workers, whilst improving the management and understanding of the project in terms of quality, cost and progress. The paper also argues that improved data reliability and robustness can be achieved by integrating the point-of-production operations into corporate ICT systems.

## 1 INTRODUCTION

The use of IT on the construction site is becoming the norm rather than the exception, with many site 'knowledge workers' utilising PC's and laptops for the management of the project. Advances in communications now allow site managers to be permanently connected to corporate systems, remain in contact with the office through the use of e-mail and be fully integrated into the construction team via web-based project management systems (WPMS). However, existing time constraints on managers, often mean that data capture is still restricted to document based systems through the completion of standard forms, reports and spreadsheets resulting in:

- islands of automation;
- duplication of data entry;
- risk to data integrity; and
- limited or no re-use of data.

Much research, both academic and industrial has taken place into the implementation of process driven mobile computing on the construction site, addressing specific construction processes such as: site diary completion (Scott,1990); progress records (Cox et al., 2002); resource management (McCullough & Gunn, 1993); quality inspections (Cox and Issa, 1996); and health and safety audits (Hawkins, 2002).

However, the majority of this work has been aimed at extending the capability of the 'knowledge worker' through the automation of maintenance, inspection and reporting tasks, and at best only filtering down to the site foreman. Whilst such developments go some way to advancing a traditionally IT scarce sector, the burden of data collection on the construction site is still carried by a limited number of personnel. A fact that could be addressed with the implementation of mobile IT at the point-of-production.

Mobile computing technologies have already been successfully deployed for once only data capture at point-of-production across many sectors. Barcodes and RFID tags are commonplace in the retail industry, couriers readily utilise mobile computing for parcel tracking and signature scanning and PDA's are being used wirelessly in hospitals for accessing patient records. However, the widespread application of mobile computing on the construction site still remains an untapped potential with many point-of-production workers effectively prevented from contributing to the information flows that exist. Many reasons have been cited for this (Bowden and Thorpe, 2002; Ward, et al. 2002) including:

- perceived high initial equipment cost;
- perceived lack of rugged devices; and
- perceived lack of computer literate workers.



This paper examines the current possibilities for integrating the point-of-production worker into corporate IT systems and presents a detailed case study showing how has been achieved.

## 2 CURRENT POSSIBILITIES IN MOBILE COMPUTING

### 2.1 Mobile devices

Research into mobile computing in construction has tended to follow the development of new devices. From early notebook type computers (McCullough, 1993) to PDA's (Cox et al, 2002). Over the past five years the number and type of mobile computing devices has rapidly expanded mainly driven by the extended capability of the mobile telephone networks. Currently the main categories of devices on offer, in order of size are:

- *Digital Pen and Paper*: a system combining a digital pen with a co-ordinate system indented on paper. As the pen writes the pattern is stored as digital text within the pen,
- *Personal Digital Assistant (PDA)*: operated by touch-screen, typically 2.5 x 3 inches in size, basic PDA's allow a user to store and retrieve addresses and phone numbers, maintain a calendar, and create to-do lists and notes. More sophisticated PDA's can run word processing, spreadsheet and industry specific applications.
- *Palmtop computer*: a hand-held computer offering similar functionality of a laptop computer. They feature a full QWERTY style keyboard and a landscape display with dimensions starting at 2.5 x 6 inches up to 10 inch.
- *Tablet computer*: utilising a larger touch-screen display, similar in size to a laptop computer these devices are capable of offering full operating systems or those similar to PDA's. Web-tablets have been developed targeted specifically at providing wireless web-based entertainment or gaming.

Of these, the PDA, palmtop computer and tablet computer are all capable of expansion by 'add-on' peripherals such as barcode scanners and RFID tag readers and many include communication capabilities of Bluetooth, WLAN or GMS/GPRS.

However, there still exists a lack of rugged hardware at a reasonable price for the construction market, one solution to this is to protect a cheaper off-the-shelf device with a rugged case such as a 'pelicase' or 'otterbox'.

### 2.2 Construction software

The majority of mobile application software has been aimed at extending traditional office-based applications, such as word processing, spreadsheets, and accessing e-mails. Within construction, this has been mirrored by the large vendors of office-based construction software such as AutoCAD and Primavera, who have developed mobile versions of their existing software. In addition, a number of off-the-shelf mobile database tools have been developed aimed specifically at building surveying, snagging and inventory control. Such tools provide a basis for customizing the software to meet the users requirements.

### 2.3 Auto-Identification

Research into the use of auto-identification techniques in construction has been active since the late 1980's with the application of 1D barcodes (Bell & McCullough, 1988). The main use of barcodes within construction to date has been in materials management with barcodes now widely used on delivery tickets such as concrete. However, the main barrier to their widespread use throughout the supply chain has been the use of closed databases, with the data on the barcode often only referring to the unique ID within the database held by the supplier.

The future of barcodes throughout all industries is now being challenged by the adoption of smarter radio frequency identification (RFID) technologies capable of transmitting and receiving data.

#### 2.3.1 Radio frequency identification

Until now, the main barrier to the widespread adoption of RFID throughout all sectors has been cost. However this is likely to rapidly change in the near future, with Wal-Mart, the world's biggest retailer, announcing plans for its 100 top suppliers to introduce RFID tags for tracking goods through its supply chain in 2005. Such widespread use will increase mass-production of the chips and could reduce unit costs to a few pence.

One example that has been explored for the use of RFID tags within construction has been in building maintenance, inspection and reporting (Yabuki, et al, 2002). When undertaking an inspection data from the RFID tag is uploaded into a PDA providing details of previous inspections and the type of work to undertake. On completion the user may upload any new changes to the tag ensuring that life cycle data remains with the building component.

"Tag and track" is a project that has been part funded under the UK's Department of Trade and Industry (DTI) ICT-Carrier programme. It aims to adapt and transfer technologies for RFID, Wireless communications and Web applications from retail



and haulage industries to the manufacturing sector supplying to the construction industry.

“Smart chips” is a project run by FIATECH, a nonprofit consortium in the USA. The aim of the project is the successful use of AutoID technology in construction applications and to realise potential benefits not identified by individual companies but by the construction industry as a whole.

#### 2.4 Mobile Ubiquitous devices

Mobile Ubiquitous devices combine a number of separate devices connected together using the body as the carrier. The main areas of research have been wearable computers and digital hard hats.

Research into wearable computers for highway and bridge inspections (Garrett, 1998; Garrett and Sunkpho 2000; Rebolj, 2000) have included a heads-up display, tablet computer, PDA, wearable computer pack and voice activated software. Commercial equivalents are now available through companies such as Xybernaut who specialise in wearable computing technologies and have developed applications for industries such as, retail, aerospace and telecommunications.

The digital hard hat has been the subject of research since the mid 1990's (Thorpe, et al. 1995, Liu, 1997) and involves a camera mounted on top of a hard hat and pictures relayed to the site office or head office using a mobile communications system. Thorpe's system included a head mounted display that could be connected to a computing device. Whilst, Liu used a touch-screen tablet computer connected to an operator with a camera producing images for inspection and reporting of infrastructure. Until recently, the technology required for efficient transfer of this information has not been readily available. However, Woh Hup Private Ltd, a construction company based in Singapore, are currently involved in a \$2 million programme to develop a commercially viable digital hard hat.

#### 2.5 Automated data collection

This technology allows for automated data capture and includes technologies such as on-board computers, built-in sensors or 3D laser scanners for applications ranging from earthworks estimating (Kanaan and Vorster 1998) to hazard identification (Changwan, et al. 2004)

#### 2.6 Identification of exemplars

Due to the fragmented nature of the construction industry and the traditional lag between academic research and industry uptake, discovering existing uses of mobile IT in construction is difficult. Even more difficult is justifying the benefits for its adoption. One such project attempting to rectify this

is COMIT (Construction Opportunities for Mobile IT). COMIT aims to promote the business benefits from the implementation of mobile IT in construction (Bowden et al, 2004).

The COMIT project has identified eleven case studies of mobile computing applications in the UK construction industry (see Table 1). The most widely adopted hardware has been the PDA, with only one project utilizing a tablet computer. The majority of identified case studies have developed bespoke software solutions to meet their process requirements, with off-the-shelf software identified in only two of the case studies, these being:

- Case A: using PDA's and RFID tags for planning and recording service and maintenance of plant and machinery.
- Case J: utilizing a blackberry PDA and enterprise server for remotely accessing e-mails.

This suggests a lack of task-orientated software being developed for the construction market.

The majority of end-users identified within the case studies can be classed as '*knowledge workers*' who are likely to use the information that they are recording during their normal working duties. In such cases, the integration of the device directly replaces existing paper-based methods with the device becoming part of the users '*tool-for-the-job*'. The case studies suggest that the use of mobile IT by the construction site production worker still remains low, with only three of the case studies identifying the end-user as the foreman or below.

It is commonly accepted that the use of IT will eliminate many of the problems directly associated with paper-based documentation: duplication, feedback, quality, exchange, awareness, illegibility, format, volume, cost, queries, and being '*out of date*' (Murray and Thorpe 1996). Whilst such benefits were observed in the majority of the COMIT case studies, a number of indirect benefits emerged as follows:

- reports produced quickly and easily,
- better customer service,
- identification of trends,
- more efficient task allocation,
- reduced task turn-around time,
- improvements in the quality of work,
- increased accountability of staff,
- reduced supervision, and
- ability to track stolen equipment.

Whilst the majority of existing initiatives may be aimed at extending mobile capability to the '*knowledge worker*' the potential for the integration of the point-of-production worker with the corporate ICT systems remains. Following is a detailed examination of one such system.



Table 1. Details of case studies captured by the COMIT project

Case study and Process	Hardware	Software	End-user
A preventative maintenance	PDA, RFID tags	Off-the-shelf	Maintenance engineers
B job allocation & timesheets	PDA	Customised	Maintenance engineers
C defect management	PDA	Bespoke	Site engineers
D fleet management	GPS tracker	Customised	Operations management
E monitoring site works	Tablet	Bespoke	Site operatives
F defect management	Digital pen	Bespoke	Foreman
G managing site safety	Mobile phone	Customised	Foreman
H timesheet & payment	Mobile phone	Bespoke	Site engineers
I earthworks examinations	PDA	Bespoke	Geo-technical engineers
J email & PIM	Blackberry PDA	Off-the-shelf	Senior executives
K field observations	PDA	Bespoke	Site engineers

### 3 THE SHERPA SYSTEM

The SHERPA system is a research project conducted within Stent Foundations Limited, a leading UK piling contractor. The project was borne out of the need to improve the quality and understanding of the progress of piling works through the implementation site data capture by point-of-production workers. Following analysis of existing practices and data flows a number of key issues emerged suggesting the use of a server-based central data repository and wireless data capture system, these were:

- multiple revisions of paper-based documentation;
- data transfer and inscription errors,
- just-in-time design data,
- real-time data sharing on site, and
- lack of data verification at the point-of-production.

#### 3.1 Hardware

Semi-rugged Windows CE tablet computers were implemented for use by the site workforce to undertake data collection (Figure 1). The main drivers for the selection of the device were:

- usability,
- integrated WLAN capability, and
- cost.



Figure 1. Windows CE tablet computer

Twenty-five tablet computers have been in operation over a period of three years with the average life-span of a device being 18 months. The most common failure being damage to the screen, which could be repaired at less cost than purchasing a new device. This suggests that semi-rugged devices are more cost effective than fully rugged devices. In addition, the payback period is significantly less, and there is no 'tie-in' to justify keeping the device for longer than necessary, a particularly important factor in a rapidly developing market where faster, and improved devices continually emerge.

#### 3.2 Infrastructure

Communication capability is provided by a site-based wireless network, which extends accessibility to the system beyond the site office to the point-of-production (Ward, et al. 2003).

The wireless network is based on the IEEE 802.11b/g wireless protocol and allows for the creation of a flexible, and re-configurable network through the use of one or a number of battery operated Wireless Network Cells (WNC). The WNC form a cellular network not dissimilar to mobile telephone network, allowing users to communicate to the site server or peer-to-peer via one or a series of WNC. WNC are typically placed on the piling rig allowing for the creation of a work zone around the rig and have also been placed on other strategic locations such as tower cranes, when available.

#### 3.3 Software

All software is based on standard web-server architecture, with all web pages located on a central server located in the site office which is used to provide localised web services to site users via the wireless network.

In order to reduce capital costs, all software utilised on the server is open-source. A MySQL database is located on the site server with all data capture undertaken through specially designed web



pages. An Apache web-server is used to deliver the content to mobile users via the web-browser located on their device. All web pages have been written using PHP (hypertext pre-processor), HTML (hypertext mark-up language) and Javascript. Server-side scripting such as database transactions and the creation of dynamic content are carried out by PHP, whilst Javascript is used for client-side interaction such as 'on-click' events.

### 3.4 Data Capture

Bespoke data capture pages have been written to correspond with the pile construction processes on the site and utilise easy-to-use, pop-up menus and keypads to aid in the data collection. The site data capture interface is divided into three distinct parts: navigation bar; menu bar; and data entry section (Figure 2).

Located on the right hand side of the screen, the navigation bar allows users access to the pile selector from which they can request the latest pile design details from the server for the current pile. Once a pile is requested the design details and construction tolerances are embedded within the navigation bar allowing them to be accessed by all data capture pages for data verification purposes and to be viewed by the user as required.

The menu bar is located on the left-hand side of the screen and includes a set of buttons, dynamically generated by PHP, each button relating to an individual data capture page.

The center of the screen is used for data capture. Users enter data by clicking on the relevant cell corresponding to the data entry to be made. An underlying continuous self-auditing process checks data entries, alerts users to possible non-conformances, and provides guidance on pile design requirements such as toe depth, cage position, levels and concrete volumes.

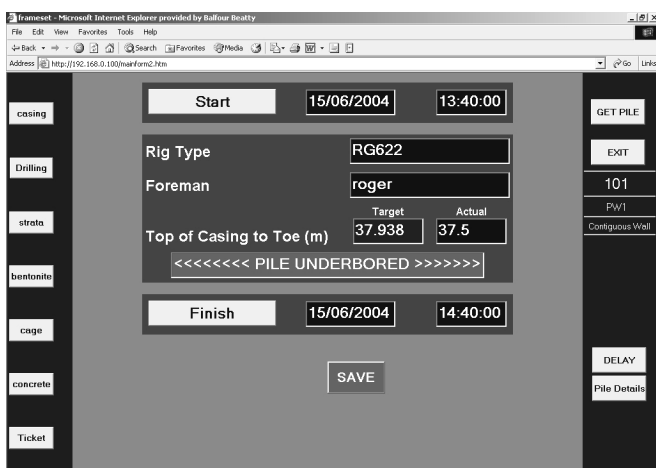


Figure 2. Bespoke web-based data capture page

### 3.5 Data Management

SHERPA allows for the real-time management of site data by the site *knowledge workers* who are able to access, maintain, manipulate and view pile design and construction data. The functionalities of the data management facility are described as follows.

#### 3.5.1 Contract settings

Contract settings provide an interface for the management of static data sets such as, concrete mix types, piling rigs, augers and expected site soil types, many of which are used on pop-up boxes integrated within the data capture pages. In addition, contract specification and tolerance details such as horizontal and vertical pile position, support fluid, maximum allowable slump and reinforcement cage position can be maintained.

#### 3.5.2 Design schedule management

One of the fundamental reasons for the design and development of the SHERPA system was the creation of a structured data source of pile design details, which could be accessed from the construction site during piling works. Emphasis has thus been placed on effective management and importing of pile design schedules. A single pile design detail is stored for each pile on the server, together with its corresponding revision, once a pile is completed, the design detail remains locked from further updates, thus ensuring integrity of design and constructed data.

#### 3.5.3 Analysis and reporting

The reporting section allows for the collation and viewing of pile data in HTML format. A number of reporting functions have been provided. Pile construction logs provide concise details of each pile and comparison to the design data. This can be further augmented with an audit summary highlighting piles that do not meet specification or specified construction tolerances. In addition concrete analysis can be carried out for individual piles, groups of piles or specific rigs based on theoretical and actual quantities used and dates of deliveries.

A prime cost analysis for materials, plant, labour and steel can be produced based on pile production for any day or period during the contract. Income is calculated by pre-processing the tender and assigning plant, labour, concrete and steel values to each pile, whilst costs are recorded through the daily input of timesheets for labour, plant returns, concrete and steel deliveries. This provides knowledge workers with a 90-95% accurate assessment of the financial performance of the contract.



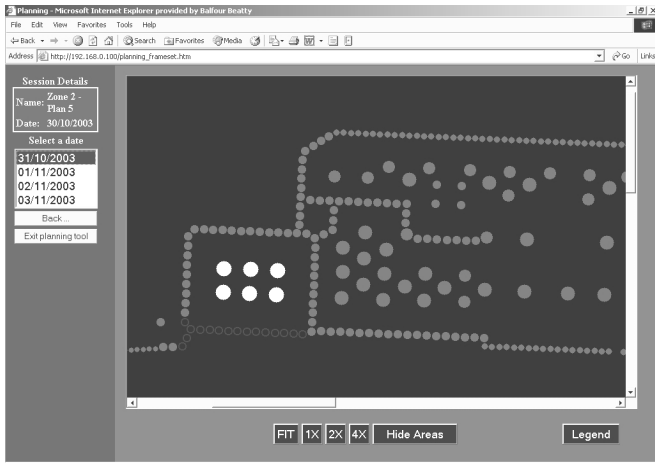


Figure 3. Visualization of site progress.

### 3.5.4 Visualisation of progress

A 'site viewer' has been developed through which a colour-coded 2D representation of the current site status can be generated using the coordinates and diameter of each pile contained within the database (Figure 3). The image created includes a pan and zoom function and colours each pile according to its current status: concreted; completed; or incomplete. Each site view image is augmented with an underlying 'click map' allowing additional pile data to be accessed by clicking on the required pile.

## 3.6 System Implementation

The SHERPA system has been implemented on various sites throughout the UK with the following observations made in respect of the component implementation and operation

### 3.6.1 Wireless network operation

Battery powered WNC have been successfully deployed on all sites and where appropriate have utilised piling rigs and tower cranes to propagate the signal across the site. A number of fundamental issues relating to the performance of wireless networks on the construction site have been previously identified (Ward, et al. 2004), as:

- uncontrollable spoil heap generation,
- variations in working levels, and
- construction of superstructure.

In addition, factors affecting the implementation of the WLAN in the early phases of the site have been observed as follows:

- the location of the site office may not be known,
- working areas may not be known,
- the site is chaotic in nature, and
- power and communications to the site office may not be in place.

### 3.6.2 Site data capture

All point-of-production workers were provided with on-site training in the use of SHERPA. Whilst

users readily accepted the reasoning behind the system, there was a level of scepticism caused by previous failed attempts by the company in introducing site based ICT. When added to the early chaotic nature of the site this resulted in a protracted implementation and training phase. In addition, the following personnel related factors significantly affected the speed of implementation.

- literacy of users,
- transient nature of site staff,
- reduced site staffing levels caused by illness, and
- level of enthusiasm instilled by the foreman on site staff.

As the SHERPA system relies heavily on the successful implementation and operation at site level, the question of how to integrate the tablet computers into existing working practices was left to the site users. In response, the site users developed a system of lecterns onto which the tablet computer could be placed (Figure 4). This resulted in the positioning of the computer at the place of work rather than individualising the units, a common feature of many mobile computing applications.

### 3.6.3 Data control

The operation and control of the system was undertaken by the site staff, with specific tasks such as schedule importing, quality auditing, pile log generation, profile management and concrete delivery analysis assigned to a number of staff on larger contracts, but easily conducted by a single engineer on smaller contracts.

The web-based architecture allows any engineer to access the system 'license-free' utilising a web-browser on any machine within the site office. Where appropriate and site conditions allow, broadband connections have been implemented on-site allowing remote users and those in the head office to access the site server and get immediate up-to-date information on the status of the piling works.



Figure 4. Use of lecterns by site staff.



## 4 ASSESSING THE IMPACT

A significant proportion of the control of a construction project is exercised by the point-of-production workers, where IT systems have been implemented for use by such workers, a number of distinct benefits have emerged.

### 4.1 *Improved quality of work*

The provision of a self-auditing system that assists the site worker in ensuring work is constructed to the specified tolerances has been shown to have a positive impact on the reduction of non-conformances on the site (Ward, et al. 2004). This has a positive financial impact on the contract and provides the client with greater assurance. In addition, there is the potential for the development of a self-certification culture, relieving the client of on-site inspection duties and therefore saving costs.

### 4.2 *Workforce productivity*

Research into the use of tablet and wearable computers by construction workers, (Elvin, 2003) suggests a slight reduction in productivity over those utilising paper-based documentation. However no difference was evident between daily outputs before and after the implementation of the SHERPA system. This is thought to be attributable to the process-orientated nature of the system which provides site workers with sufficient time to complete the relatively small amount of data input required. In addition, the reduction in defects from the implementation of systems such as SHERPA and consequent delays for rectifying work are likely to be a contributory factor.

Typically one to two hours per day are spent by the foreman collating and completing paperwork such as concrete records, concrete tickets and pile logs. This was eliminated in the SHERPA system allowing the foreman more time on the site to undertake a supervisory role.

### 4.3 *Improved workforce knowledge*

Providing point-of-production workers with process-related IT systems allows for a greater understanding of the main factors affecting the quality of construction, either through underlying self-auditing such as that observed in the SHERPA system or by asking specific questions of the user. Where previously consideration has been on the speed of production, the implementation of IT can be used to force site users to consider the quality of construction. In addition being able to access the correct information at the right time is essential to avoid rework.

Currently, many construction workers are excluded from the information loop providing guidance on current site progress in terms other than production or work scheduling. This is particularly true of financial information, which many companies see as sensitive. Such an approach reinforces the 'them and us' attitude between site workers and their *knowledge worker* counterparts. Systems such as SHERPA help to redress this balance by allowing site managers to produce a variety of reports and graphs that can be distributed to the site workers helping them to improve their understanding of why certain management actions need to be taken and the benefits from doing so.

### 4.4 *Timely access to data*

Site office based personnel report the greatest benefit from such systems being the improved accessibility of data coming from the construction site. The capture of data at point-of-production eliminates duplicity whilst time for collation and analysis of data have also been found to be reduced. This improved accessibility and management of data in turn reduces the turnaround time for signing-off work and establishing grounds for payment.

### 4.5 *Better understanding of site progress*

Allowing point-of-production workers to contribute their process and production related data direct to corporate databases improves the understanding of site progress not only for the site *knowledge worker* but also for those workers residing at the head office. At best, head office workers are able to access point-of-production data in near real-time using a direct link to the site, whilst at worst a view of the previous days progress can be achieved when the transfer of data is by GSM dial-up.

Historically, project progress and costing has been based on accounting principles, with knowledge of project financial progress limited by the valuation process. Such methods allow for the concealment of real progress by site engineers and have a distinct effect on short-term projects that may be completed before the real financial picture can be made available. It is envisaged that through the capture of production data by the point-of-production worker difficulties caused by traditional practices can be drastically reduced.

## 5 CONCLUSIONS

Whilst, there are many efforts currently underway to integrate mobile computing into the construction



workforce, many of these are targeted at the 'knowledge worker' level of the business, the possible reasons for this are:

- the development of off-the-shelf task specific software,
- a more accepting workforce, which eases the implementation, and
- the IT becomes part of the users working tool.

However, the development and implementation of the SHERPA system has highlighted the ability to extend corporate ICT systems to the point-of-production worker.

Benefits to both site workers and *knowledge workers* have been highlighted which suggest a substantial improvement in the quality of work, accessibility to data and understanding of site progress. In addition, data visualisation techniques have been used to validate imported data, monitor site progress and assist with pile planning and sequencing tasks.

Whilst the example presented has been developed specifically for the piling works site, the SHERPA approach has the potential to deliver web-based project management support to construction site workers in a range of disciplines.

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