Theme:

Title: **Mobile Computing in Construction**

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Abstract: *This paper initially presents the potential use of mobile computing in the construction industry. However, it is further assumed that the use of mobile computing can significantly improve the flow of relevant information among the project participants only if the present organisational culture is subject to changes. That is further supported with the results from the experimental study of the potential use of various mobile computing devices in the project information exchange procedures. In this respect only cost effective, commonly available and standardised solutions would prove a project-wide applicability. The final objective of the paper is to show why should be further research on mobile computing more focused on identifying the weaknesses of the present project information exchange procedures and their optimisation according to the applied IT in order to employ all of its advantages.*

Keywords: *mobile computing, project management, construction industry, construction site e-construction*

## Introduction

One of the major problems in using information technology (IT) in civil engineering is the fact that production (construction) activity is dispersed and site locations frequently change. Compared with other industries, this has proved a great disadvantage in giving construction sites adequate IT support. Computers require infrastructure, which has slowly been transferred to the site office, but never to the construction site itself in any systematic way. Therefore, the impact of IT on the way the construction industry actually works has not been significant so far.

Some authors have already noted that the impact of most research results in the field of construction IT have not had a significant impact on the construction industry in general (Björk 1999, Turk 2000). Most construction IT solutions, like integrated building models (including complex product and process models), require highly organized and standardized project environments, which are not found in real-life construction projects. Partners in a construction project consortium are typically at very different levels of organization and IT use. Therefore, they are forced to use mutual digital communication at quite a low level. There have, however, been some “minor”, typically isolated IT solutions which did have a tremendous, albeit not mainstream, impact on the construction industry (telefax machines, mobile phones). Unfortunately, in such a case the level of process automation was nearly zero, but at least distance was not such a problem any more.

During the past few years another device has evolved to a mature level – the handheld personal computer (HPC), or personal digital assistant (PDA), as it is more often called lately. Its speed, memory capacity, communication possibilities, reliability, small size and long power independence, as well as its level of hardware and software standardization, gives the PDA a powerful potential in the information chain of a construction project. This is true, however, not on an isolated, individual level, but rather in an integrated and systematic way, which means an organized combination of PDAs, mobile phones providing wireless data transmission, and network-based document management.

This paper consists of two main parts. The first part defines the concept of mobile computing, describes some recent research, and spells out the potential for the construction industry. The second part is focused on a case study – an experimental project in which we tried to make systematic use of mobile computing at a real building site. The paper concludes with some suggestions for the future development and use of mobile computing in construction.



## Mobile computing

*General overview*

The term mobile computing is quite new and has no clear definition, although some studies have already tried to survey this fast-growing area of information technology. Mobile computing does not only involve mobile computing devices (laptops, notebooks, PDAs and wearable computers), which are designed to be carried around, but also the mobile networks to which these computers are connected. Mobile services are the third component, rounding out this definition of mobile computing.

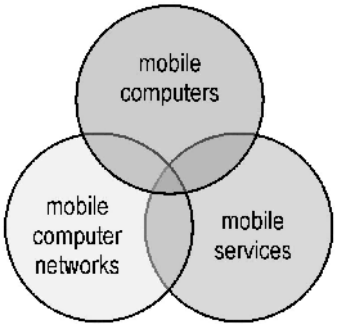


*Figure 1. Concept of mobile computing*

In this sense, some earlier papers addressed the specific problems of mobile computing, like designing mobile computing systems using distributed objects (Chen, Sauda 1997), but the most relevant research reports can be found only in more recent publications. Interesting topics include: mobile client-server computing, including mobile-aware adaptation, an extended client-server model, and mobile data access (Jing et al 1999), interaction with the World Wide Web via wireless-connected PDAs, problems with bandwidth limitations, screen real-estate shortage, battery capacity, and the time costs of a pen-based search keyword (Buyukkokten et al 2000), client/agent/server adaptation of a framework to enable performance improvement, which is very important on slow or expensive networks (Papastavrou et al 2000), and data management, including data dissemination over limited bandwidth channels, location-dependent data querying, and advanced interfaces for mobile computers (Barbara, 1999). We agree with Zimmerman in emphasizing the evolution of PDAs as the engine driving mobile computing. Pocket-size, low-price units with long-lasting power autonomy and broad functionality guarantee the critical mass of buyers necessary to motivate the industry to produce and further develop this type of device. The opposite of integrating functions in a single device is device modularization, which has some additional positive effects. A small mobile phone with data transmission capability can be connected to a PDA or another more specialized device, thus offering them networking capabilities. However, integration versus modularization is an old dilemma, one which is not very significant in the present case.

Although the number of research papers addressing mobile computing is modest, there is no doubt that much research is going on, perhaps even too fast for papers to be published. As one technology overtakes another (Jefferson and Orubendo 2000, Murphy 2000) it is probably wiser to concentrate on more general concepts and problems. One such problem is the adaptation of existing information systems suitable for efficient integration with mobile computing. In this regard, we agree with Vizard that “until then, mobile computing will just remain a troublesome niche application for those who can afford to pay for it”.

## Mobile computing and construction industry

One of the most significant characteristics of the construction industry is that the locations of its production sites frequently change. Since one consequence of this fact is fieldwork, mobile computing is of great importance for the construction industry. Despite this, there are only just a few publications that address the use or the potential of mobile computing in construction.

One might think that solutions already exist (at least for those companies with a high level of IT), since many software vendors already offer extensions of their successful products for PDA operating systems. In the field of project management, we can even find integrated solutions which not only include mobile extensions, but are actually built upon the mobile computing concept. Recording project data, such as

supply delivery records and progress updates, directly at the jobsite is one of the basic functionalities of such systems (Bidcom, 2000). Third-party extensions to commonly-used project management systems already exist as well (Onsyss, 2000). More complex systems include a comprehensive suite of hosted internet solutions that facilitate rapid communication and collaboration throughout the entire project life cycle, from financing and planning through engineering and design, procurement, construction, and facility management (Citadon, 2000). Document management systems provide construction teams with a project-specific extranet, whereby remote team members can communicate and access up-to-date documents. Further, such services alert users affected by changes in real time via e-mail or a pager (King 2000). Another approach has been discovered in Japan, where the Daito Trust Construction Company developed a large-scale mobile computing system called the DK Network (Daito, 2000). The company reports that, the system made the process of construction easier and greatly increased productivity. It remains a question, however, how many companies working together on a construction project would be able to follow this approach. For most of them, standard devices and services have to be available on the market at affordable prices in order to be attractive.

While speaking of special devices, we should also mention wearable computers, which could be highly applicable to construction activities. The main characteristic of these highly integrated systems, which include all the necessary input and output devices, is that the user's hands are left free (Xybernaut, 2000).

In the field of construction, drawings are among the most important types of documents, and therefore software for managing them is a necessary requirement for mobile computing in construction. AutoDesk's OnSite View offers viewing, mark-up design changes, on-site project document queries using digital measurement tools, and synchronization (Hernandez, 2000). Geographic Information Systems (GIS) are already available for some PDAs as well.

Based on this short overview, we can conclude that some important experience has already been gained, and that the main building blocks for mobile computing in the construction industry are already available on the market. There is, however, no evidence of any systematic research in the area of mobile computing in construction. Yet there are quite a few important, still open questions that should be addressed: how does mobile computing work on site, what organizational changes are required, are the common commercial mobile phone network services sufficient for mobile computing in construction, how complex is the problem of integrating mobile computing into existing information systems (which are still not integrated to the desired extent themselves), what educational efforts will be necessary, and so on. In order to find at least some of the answers, we decided to conduct an experiment.

## Case study

In January 2001 a multipurpose experimental, educational and research project called Mobile Computing at a Construction Site (or e-site, for short) began at the Faculty of Civil Engineering of the University of Maribor. The project is being conducted by the Construction IT Centre and carried out by students in the 4th year Civil Engineering and Industrial Engineering programs, some postgraduate students, and engineers from the construction industry. For undergraduate students, the project is a part of a regular subject entitled Construction IT, which is the last in a series of IT subjects in the curriculum.

## Project plan

A road construction site was intentionally chosen for the experiment, since one of the most important research fields at the Construction IT Centre is road product and process modeling (Rebolj, 2000). Through this project we wanted to explore the potential of the latest commercially available mobile devices connected via GSM high-speed data links to a web-based project information system, which allows construction project documents to be exchanged. Additionally, we planned to test available CAD and GIS software and integrate it into the document management system.

The main goals of the project were to:

- examine the characteristics and potential of commercially available PDAs for the construction industry,
- examine the possibilities for using available GSM mobile phones and services for data transmissions in a construction project network,

- examine the potential of and requirements for efficient mobile computing at a construction site and in civil engineering in general,
- determine the real information flow at a construction site, real information and functional needs, and bottlenecks and problems in providing information,
- examine the possibilities for supporting construction site information flow with mobile computing, and
- provide a document management system for mobile computers, including suitable software for processing these types of documents: texts, spreadsheets, drawings, maps, pictures, and video.

Four groups, responsible for the following specific areas, carried out their activities in parallel:

1. Existing hardware, software and organization on site and in related offices
2. Mobile computers and suitable application software
3. Wireless communication technology (local networks, mobile phones and services)
4. Project management, implementation of document management system, coordination between groups

### Project procedure

The first task of the project was to analyze the current organization of information exchange and the structure of data at the selected building site. The data flow diagram (DFD) technique was used for this purpose. A basic DFD was elaborated (Figure 2), serving as the main scheme to which all other findings were linked: document origins and destinations, data structures, document formats and carriers, IT support, and persons responsible.

In the second task, which ran in parallel, available and suitable forms of mobile information technology were examined. We discovered that, while a great deal of software is already available on the market, software for engineering purposes is at present mainly available for the Windows CE operating system. The decision to use this operating system narrowed the selection of suitable devices down to just a few, which run on the latest version of Windows CE. We found Cassiopeia E-125 the most appropriate for our purposes, since it has a compact flash slot for additional hardware extensions – including a small video camera.

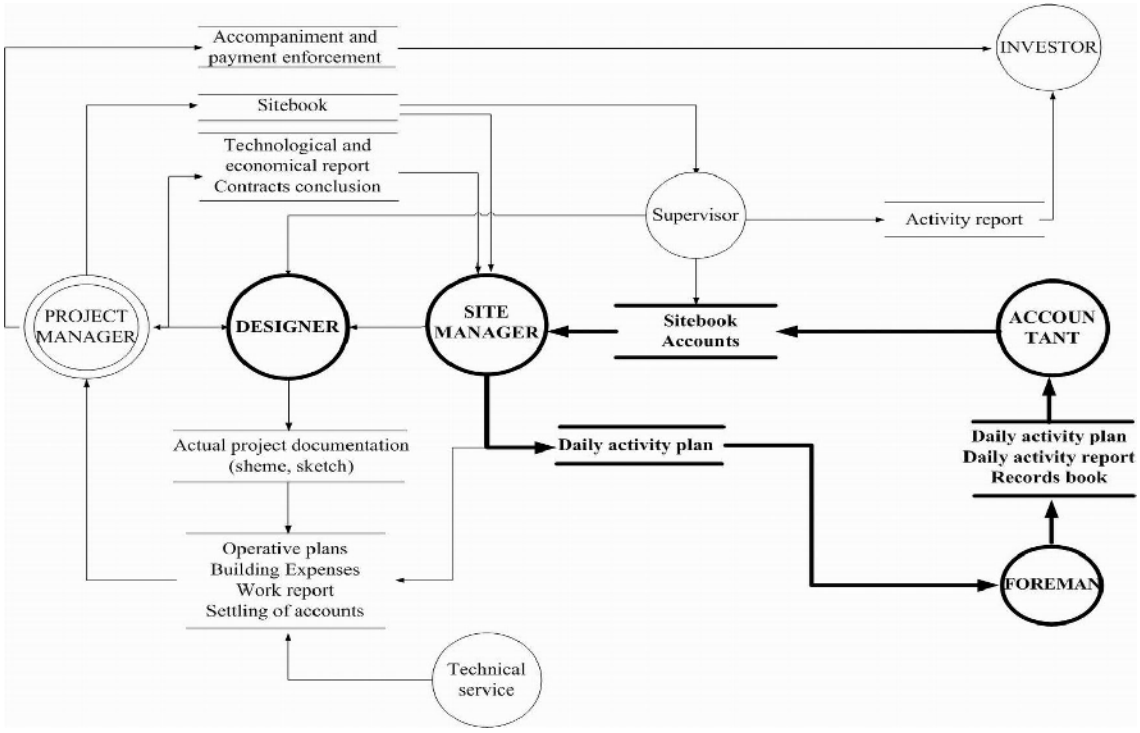


*Figure 2. Main data flow diagram*

After choosing the operating system, the device, and additional hardware extensions (memory card and video camera), we selected the following software for use in the project: Internet Explorer (included in operating system), Pocket Word for text processing (included in operating system), Pocket Excel for spreadsheet processing (included in operating system), Mobile Picture & Video Player (comes with the Casio camera), OnSite View for viewing and marking drawings (Autodesk), ArcPad for processing geographical data (ESRI).

Another group examined mobile (wireless) communication services and devices, which are being developed extremely fast and are widely used. The second generation of mobile networks and devices (GSM) was analyzed more closely, with a special focus on data transfer. For this purpose, a set of files was prepared, representing all types of documents that the document management system should support, and for which appropriate mobile software had already been chosen. Download times for documents from the Internet were measured using the mobile device and the NOKIA 6210, once with normal data transmission speed and once with high data transmission speed using HSCSD. Unfortunately, we were not able to measure data transmission with GPRS technology. Additionally, we calculated the minimum transmission time, in terms of the maximum speed available with a particular GSM data transfer technology. Part of the results, which give very important information about the availability of certain document types, are shown in Table 1. In this regard, availability can be understood as the readiness of the user to wait for a certain document.

The next task again focused on the data flow diagram. We determined which information flows were most suitable for mobile computing support (thick lines on Figure 2). The selection criteria considered were: information exchange frequency, importance of information, and transmission time.

Although the building company we worked with has a relatively good level of IT use, most documents circulating on site are in printed form and have a limited data structure, which made them unsuitable for direct use in our mobile computing system. Therefore, all existing documents supported were redesigned and converted into more appropriate data formats, which were supported by the selected application software. In most cases, we decided to use spreadsheets, since they give a clear data overview and enable simple data input.

| | Selected document types, sample files and their size in bytes | | | | | |
|---|---|---|---|---|---|---|
| Data transmission time in seconds | Text (Plan.pwd) 1126 B | Map (Landuse.*) 11930 B | Picture (Column.jpg) 64474 B | Drawing (Axis.osd) 400384 B | 12s video (View.cmf) 516096 B | Speed [bps] |
| basic, meas. | 1.5 | 14.5 | 98 | 523 | 775 | 5823 |
| basic, calc. | 0.94 | 9.9 | 54 | 325 | 430 | 9600 |
| HSCSD, meas. | 0.7 | 2.8 | 19 | 112 | 137 | 30016 |
| HSCSD, calc. | 0.21 | 2.2 | 12 | 72 | 96 | 43200 |
| GPRS (high), calc. | 0,08 | 0.83 | 4.5 | 27 | 36 | 115000 |

*Table 1. Measured and calculated data transmission times (in seconds) for typical documents using available GSM technologies*

In the case of drawings, we had to convert them from the AutoCad format, in which most were available, into the OnSite View format. The conversion itself was not a problem, since both products come from the same vendor and conversion software was available. However, the size of the drawing files doubled, which was very inconvenient in a relatively slow communication network. All other files converted from PC (Windows) to PDA (Windows CE) formats became much smaller. The size of text files and spreadsheets decreased by a factor of 5 to 20.

Although the plan was to design and implement a document management system that would respond to all requirements, we decided to use an existing web file system instead. The primary reason was the main concept of the project, i.e. to make use of existing components. Another reason was the fact that we had no experience with users' practical demands. The system we used was offered by a software company, which built the web file system as a service to its own clients (CGS, 2001). The web file system offers the following functionality: password-protected projects with multiple directories, each containing a flat set of files, every directory is linked to a list of users, each of whom has an electronic address for system

messaging purposes (e-mail or mobile phone number for SMS messages), uploading and downloading files, activating software for supporting file types, alerting users to file changes in their directory (each message contains the time and type of change, and the name of the user who made the change).

Many separate tests were performed throughout the project; these were necessary to prepare the scenario for the final test, for which three groups were created to play the roles of the site manager, the foreman and the accountant. The site manager and accountant used PCs with a permanent connection to the Internet, running Windows operating system, MS Office and AutoCad. The foreman used Cassiopeia E-124 with a video camera and a Nokia 6210 GSM terminal, connected to the PDA by a cable (Figure 3).

*Figure 3. The foreman's equipment*

The PDA ran on Windows CE 3.0, with Pocket Word, Pocket Excel, OnSite View and Mobile Picture & Video Player. In the document management system, one directory was opened for each communication channel: Site Manager-Foreman, Foreman-Accountant and Accountant-Site Manager. E-mail addresses were given for contacting the site manager and accountant, and a mobile phone number for contacting the foreman via SMS, since it was not planned for mobile devices to have a permanent connection to the Internet. The final test was performed according to the scenario, with the following steps:

The site manager uploaded the daily activity plan to the Site Manager-Foreman directory. The foreman got an SMS message within a minute, telling him that a new daily plan had been uploaded. He established a connection to the Internet, logged into the web file system, and went to the new file, which appeared in PocketExcel within a few seconds. The foreman commenced activities according to the daily plan.

The foreman perceived a problem with a newly built column, took a picture and wrote a comment. He again established a connection to the web file system and uploaded both files to the Site Manager-Foreman directory. The site manager was alerted immediately. He prepared a solution in form of a drawing and a comment, modified the daily activity plan, and uploaded all three files back to the Site Manager-Foreman directory.

The foreman received the modified daily plan and proceeded with the modified activities using the downloaded drawing. After finishing the work, he made his remarks on the drawing, filled out a report

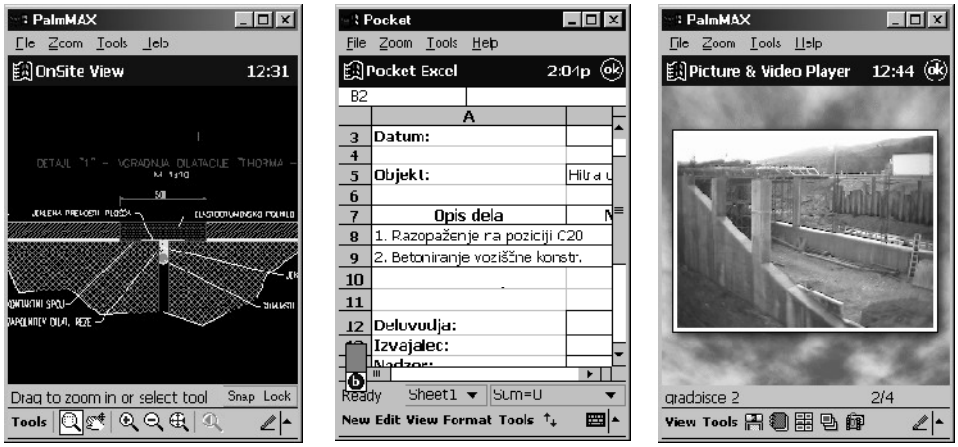


*Figure 4. Display on PDA; OnSite View, Pocket Excel, Mobile Playert*

and uploaded both documents to the Foreman-Accountant directory.

The accountant received the message, opened the daily report, processed it, and uploaded the updated book of records together with all received documents to the Accountant-Site Manager directory. The site manager received the message and inspected all documents.

## Project results

The final test showed that the efficiency of information interchange with and at a building site can be improved significantly even by using current mobile computing components: unmodified, currently available PDAs, mobile phones and web services. To reach their full potential, however, some improvements would be inevitable.

The commercially available PDAs that were used in the project already offer abundant functionality and processing speed; they are not, however, suitable under stress conditions (dust, strong light, rain, handling by workers, etc.), which are normal at a building site. Data input is another problem, which needs to be addressed seriously in the future. There is also the ever-present problem of screen size: either the screen is too small for a good information overview, or too big to fit in a pocket. Our experience is that devices not fitting into a foreman's pocket will not be carried around, but rather left back at the site office.

A cable connection between a PDA and a mobile phone proved to be a satisfactory solution, since the mobile phone can stay in the pocket when connecting to the Internet. There is, however, a problem with finding suitable cables, since both types of devices used non-standard connectors. The only standard data connection is IrDA, which was not suitable for our purposes. For the future, however, the wireless small area network seems to be the perfect solution. In this way, people in the same area could share documents as well as special devices instantly. The transmission speed available from current wireless network technology is a problem in the case of documents larger than 100 KB (drawings, video), but not for text files and images. It is expected that this problem will be solved by the new mobile phone generation (UMTS), with data transmission speeds measured in megabytes.

One of the most important components of the mobile computing system that needs to be improved is the document management system. It became evident that a process model should be used as the basis of such a system. In this way, data flow could be fully automated and individuals would not have worry about which communication link to choose or which file to download or upload in order to exchange the desired information. A user-friendly interface (client software) to such a document management system would be required as well.

Another significant improvement would be using structured information instead of conventional documents. In this way, information automation and integration would be possible. In our project, only selected document types could be interpreted using the selected software, and no data integration was possible. Non-standard data formats also made it necessary to convert some document types so that they would be usable with software running on a PDA. A standard means of structuring and describing data (like XML) could solve these problems. On the other hand, a product model could serve as an integrator for all the information needed (Rebolj, 1999).

## Conclusion

The aim of this paper was to objectively describe the potential of mobile computing for the construction industry. We have intentionally not focused on special devices, prototype equipment and concepts, which cannot be used right now, or which would require high investments. Instead, we concentrated on commercially available mobile devices, software and services that can be easily obtained for a reasonable investment. Our case study showed that significant improvement of information exchange with and at a building site could be achieved by systematically organizing existing components. It may be expected that these components will develop quickly, thus improving the efficiency of mobile computing in the construction field even further. On the other hand, information systems in construction will have to be redesigned and improved so as to attain a higher degree of information integration and a higher efficiency of information flow. Anyhow, it is obvious that mobile computing will play an extraordinarily important role in the future of the construction industry. This fact encouraged us to continue with research and try to find solutions to the many open problems.

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