World Conference on IT in Design and Construction, INCITE/ITCSED 2006, 15 - 17 November 2006, New Delhi. (pp. 353-364, Vol.1)

# Usability evaluation of mobile ICT support used at the building construction site

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## Abstract

The paper summarizes findings from field evaluations and controlled laboratory usability evaluations of new mobile Information and Communication Technology, ICT, support used by craftsmen at construction sites as well as a discussion of methodologies for user centred ICT tools design. The findings are derived from the Danish project 'IT at the Construction site' started in 2003 and ended in may 2005. The project is now followed up by the newly started 'IT and resource management at the construction site' project. The project has involved several small to medium sized construction enterprises, organizations and institutions within the building domain as well ICT tools providers. The Danish Ministry of Science Technology and Innovation financed the project.

Several ICT tools were used in the project including mobile telephones with barcode input, PDAs, GPS-systems and wireless computer network access at the building site. The main support systems under consideration were for resource management and time reporting on activities as well as knowledge management at the construction site.

Usability field tests were carried through at full scale construction site laboratories at the Vitus Bering institute in Horsens Denmark in collaboration with the department of Computer science and department of Building technology at Aalborg University. Controlled laboratory tests were as well carried through at Aalborg University. A think-aloud technique followed by a NASA-TLX test for registering of user stress during test was used. The test procedure and the test tasks are described in the paper.

Some of the positive findings are; there is a great potential in barcode recording of especially components, material and driving activities. This can well be done using mobile phones. The user interfaces must be further developed and take into account specific user interaction requirements as well as technical stability of barcode readers and long response times over the GPRS network. Some basic heuristics were not fulfilled such as informative feedback on certain user actions and the user in charge of operations and clear indications of status for different ongoing activities in the systems. The end users were in general rather satisfied with the performance of the tested systems.

The project has pointed out that the time needed for user needs and requirements capture was underestimated, as is very often the case. Therefore the paper also explains and comments on methodologies for user needs and requirements formulation that are also used in student collaboration projects with industry at Aalborg University.

## 1. Introduction

The project 'IT at the construction site' was started grounded lack of assembled activities to better utilise and develop Information and Communication Technology, ICT, tools at the building site. The project was launched in 2003 and ended in May 2005. The project is now followed up by the newly started 'IT and resource management at the construction site' project. The project has involved several small to medium sized construction enterprises, organizations and institutions within the building domain as well ICT tools providers. The Danish Ministry of Science Technology and Innovation financed the project.

Many ICT domains were covered by the project

- Construction web portal
- Digital document handling
- Mobile telephone technology for registration
- Education activities
- Collaboration between industry and research institutions
- Evaluation of construction site ICT tools
- Knowledge transfer

This paper focuses on the results and methods used in evaluation of mobile ICT support used at the building construction site. The results from the project are used by the participants in education at Aalborg University and Vitus Bering institute in Horsens Denmark.

It is concluded from the project that small building construction firms' use of ICT tools in production still is limited. Some of the barriers recognized in the project are:

- Limited understanding of possible achievements by using ICT tools.
- Limited overview of possibilities and barriers.
- Uncertainty regarding ICT implementation costs.
- Poor connection between existing ICT systems.
- Fear of being dependent on ICT tools.

The main conclusions are:

- The companies shall be prepared for the change in ICT tools support, and are keen to hear from other companies' experiences.
- Anticipated effects shall be described and evaluated to increase insight into investment goals
- Collaboration between companies, system deliverer and university is necessary for efficient development and implementation of systems.
- Knowledge transfer routines should be improved.
- System usability and interoperability must be improved including business ontology development.
- Increased focus on education within IT in construction is needed.

The ongoing national Danish Digital Construction R&D program, DDB, will give important input to classification and use of building product and process models, see also (Christiansson & Carlsen, 2005). Four projects were launched in 2003 within client requirements formulation, (1) Digital tender, (2) 3Dmodels, (3) Digital handover (Digital aflevering), DACaPo, and (4) Projectweb together with a project on Foundation for Digital Construction (classification and standardization issues). Public clients must from January 2007 use requirements standards within mentioned areas.

## 2. Today's and tomorrows ICT support

### Project experiences

Based on interviews with participating companies figure 1 shows today's and tomorrows situation with regard to ICT support. Focus support areas were administration and

- Planning of man resources.
- Time registration.
- Registration of materials and equipment on projects (and cases/activities).
- Integration with existing administrative systems at the companies.

Much of the administrative work in the studied SMEs were done by master or his wife and partly in paper-based systems with less likelihood of value based re-use of data.

The participating companies listed requirements on future systems that they meant should be paid attention to (see the grey arrows in figure 1).

- Reduction of double registrations.
- Secure digital registration of time- and resources spending.
- Registration of purchases.
- On-line access to detail planning system.
- Utilization of data through many systems (systems interoperability).

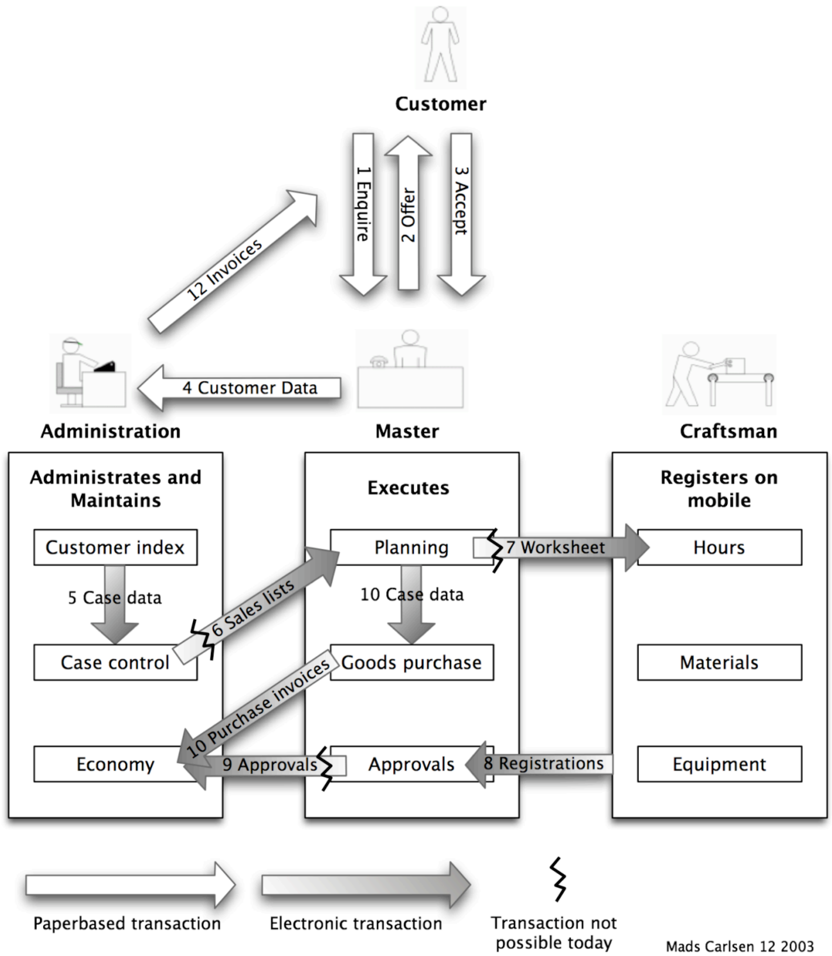


Figure 1 Information resources with indication of where digital flow can be accomplished today, (Carlsen, 2003)

Figure 1 shows the craftsman registering his consumptions on his mobile phone. The data are immediately transferred to Master/the Boss, who will be constantly updated on information on the consumptions on each activity in the projects, facilitating planning of resources allocation. The participating companies have in the project field-tested devices and systems for time-, material-, and equipment management as well as planning.

In figure 1 is shown with zigzag lines what transfer could not be made electronically during tests. For example problems are reported on data format reported when sending from registration system to administrative systems (activity 9 in figure 1). The participating system providers solved some problems during the tests. System interoperability remains as one big hurdle to overcome. Time registration on mobile devices was well received after a short running-in period.

## ICT development

ICT support has slowly since the early eighties been introduced at the building sites. At first as stationary computers and later with the spread of wearable computers and the introduction of LCD screens as personal wearable ICT support. In 1991 the vu-man was delivered to easily handle digital documents presented at a head display during maintenance work. From http://www.ices.cmu.edu/design/VuMan.html "The purpose of developing the vu-man (pronounced view-man) wearable computer was to improve the maintenance process on complex machines. It was developed for use by commercial airlines, the automotive industry, and any other organization involved in inspecting, training or repairing complex machines."

From http://www.new-technologies.org/ECT/Civil/digitalhardhat.htm. "The Digital Hardhat (DHH) technology enables dispersed users to capture and communicate multimedia field data to collaboratively solve problems, and collect and share information. The DHH is a pen-based personal computer with special Multimedia Facility Reporting System software that allows the field representative to save multimedia information into a project-specific database, which is then accessible to others through the World Wide Web". The DHH was delivered 1996.

wearIT@work, 'Empowering the mobile worker by wearable computing' 2004-2008 http://www.wearitatwork.com/, is a EU Integrated project funded under 6th FWP (Sixth Framework Programme). The project covers many aspects of wearable computing with results also valid for the building industry. Construction site experiences are reported in (Ward et.al., 2004) where a mobile site level data collection system was implemented for piling works utilizing the IEEE 802.11b wireless protocol and tablet computers.

From (Wood & Alvarez, 2005) An " "auction" was designed to rank the candidate technologies in terms of near-term perceived value. "Bidders" were told they had an imaginary $1 M budget that they must spend in a sealed bid auction of new construction/maintenance technology. This new technology would be available to support a major project on that organization's horizon". See figure 2. See also (IJACS, 2004).

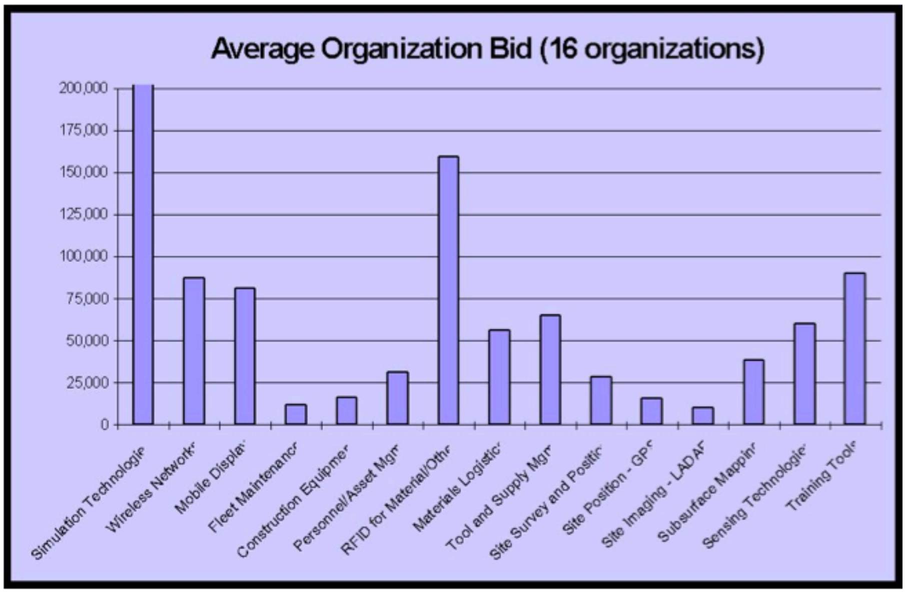


Figure 2 "Technology "auction" designed to rank the candidate technologies in term of near-term perceived values". From (Wood & Alvarez, 2005) page 10.

In summary we are in an intense period of development where we can do creative design of future user environments. High quality models of building products and processes can be used in augmented reality environments to make collaboration and 4D simulations more effective, supported by underlying models and efficient data transfer. The upkeep of correlated consistent distributed models will be better supported through common classifications, standards and vocabularies. Products and building components may contain information about for example properties and maintenance instruction through embedded RFID to support handling and intelligent behaviour in the completed building. Standards on wireless communication, agreements on business ontologies (missing today) and web services will provide ground for a development resulting higher qualities on products and work.

## 3. User needs and requirements capture

End user involvements in introduction of new ICT support tools are very often heavily underestimated. In many cases narrow decisions are made at top level on introduction of a certain ICT support with a reduced holistic view regarding user needs and requirements, and relation to existing tools with respect to data transfer, reuse and storage.

It is thus important to define user involvement with regard to user needs and requirements capture, functional user environment design including computer user interface, and continuous end user evaluations. The traditional evaluation on system efficiency, effectiveness (do the system solve the targeted objectives), and user friendliness (how well do the system meet user expectations on the system) must be evaluated during system development and implementation.

We have used Contextual Design methodology (Beyer & Holzblatt, 1998) for formal process description to strengthen development documentations and communication between project participants. We have been using this approach with good results for several years also in education and student projects with industry. See also (BI, 2006).

In a continuation project 'ICT and Resource Management at the Building Site' we use the same approach to develop a ICT support change process methodology.

# 4. Tests

## 4.1 Methods and test cases

The usability evaluation paradigm used was laboratory usability testing in a usability laboratory at Aalborg University and a field laboratory at Vitus Bering. Users were observed by recording think-aloud, several video cameras and user activity logging in tested system and ended by a NASA-TLX test for registering of user stress during test. 4 master students at department of Computer Science conducted the tests, carried out in March 2004. 7 end-users participated in each laboratory test. The 14 test persons were aged between 18 and 36 years, with average to high experience using mobile phones, almost none experience of WAP services, and beginners in using mobile phone scanning devices. See (Nielsen et.al. 2004a) and (Nielsen et.al. 2004b).
They were asked to solve 9 tasks. The 9 test tasks were in short:

1. You are going to Mr Hansen to change a water stop cock in a ceramic tile. Set-up the task.
2. You have the following material and equipment in your car.
   The following equipment shall also be brought and therefore registered
3. You drive from the office to Mr. Hansen. Register driven km
4. After installation register the material used.
5. Another person from the company passes by and wants to borrow your flat chisel. Remove the equipment from the task.
6. You take a 10 minutes break. Register this in the system.
7. You discover that you only used 2 tiles and registered 3. Correct this information in the system.
8. You now get order from Master that you should continue on another task nr. yy, which is not completed. Start this task in the system.
9. Time to finish the day's work. Continue task tomorrow. Correct used time for today's first task (you actually started it 1 hour earlier).

Each test sequence included the following activities:

- Registration of test person and his experiences with IT, Internet and Mobil phones, WAP and barcode scanners
- Introduction and presentation of equipment
- The test case delivered on paper for each case; max 40 minutes running true the test, possibilities to ask for help on directions to go.
- After the last test case the test person was asked to fill in a NASAS-TLX test.
  From (FAA, 2006)
  "NASA-TLX is a subjective, post-hoc workload assessment tool. NASA-TLX allows users to perform subjective workload assessments on operator(s) working with various human-machine systems. NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. The subscales include Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration."
- Finally questions on their views on the test and the systems In total 12 questions with answers graded 1-7.

Three mobile resource management systems were used by the participating companies, namely NetMill, http://www.denmobilemedarbejder.dk/, EasyTime, http:// www.easytime.org, and Reeft, http:// www.reeft.dk.

## 5. Laboratory equipment and mobile devices tested

The Netmill system was used in laboratory and field tests. It uses barcode reader for input that may ease input at the building site where gloves may be a hindrance when using a keyboard on a mobile device.


Figure 3 Ericsson T68i Mobile phone equipped with barcode reader scanning a laminated barcode sheet.


Figure 4 Ericsson T68i Mobile phone mounted on video stand for capture of mobile phone keyboard and screen. The video camera is wirelessly connected to video recording device.


Figure 5 The laboratory test facilities at Aalborg University.

### Test results

There is a great potential in barcode recording of especially components, material and driving activities. This can well be done using mobile phones. The user interfaces must be further developed and take into account specific user interaction requirements as well as technical stability of barcode readers and long response times over the GPRS network. Some basic heuristics were not fulfilled such as informative feedback on certain user actions, sometimes missing feed back on system status, not clear error codes, the user in charge of operations, and clear indications of status for different ongoing activities in the systems.

Barcode puts higher demand on language definition. That is the sequence of inputs to build a correct input for the system, e.g. crane, start using, ....... crane stop using,..... start drive,..... stop drive i.e not consistent command sequences. Sometimes inconsistent use of barcode-generated commands (for equipment and material) was reported as well as sometimes too long response times.

Many complained that they could not see if the telephone was fetching data. There is a small icon on the telephone giving status feed-back, but due to lack of proper introduction many users were not aware of this, and the not standard user interface on mobile telephones. The input/output procedure will probably also be enhanced with use of larger display and text/graphic input devices.

The project has pointed out that the time needed for user needs and requirements capture was underestimated, as is very often the case.

The end-users were in general rather satisfied with the performance of the tested systems and gave very positive feed-back from some users on the prospect of better control on resource use.


## Acknowledgements

The Danish Ministry of Science Technology and Innovation financed the research. A special thank is given to the participating companies Murer- og entreprenørfirmaet Hans Ulrik Jensen A/S, Ødsted Tømrer- og snedkerforretning Knud Kyndesen, Malermester Jørn Johansen, Byggeriets IT A/S, and Vitus Bering CVU.

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