Implantation strategy of mobile technologies in construction

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ABSTRACT: Small and medium sized enterprises in the AEC sector most often are lacking human and financial resources to implement and test mobile technologies within their businesses. Consequently, SME do not benefit from the various advantages of integrating field personnel into the company's IT-infrastructure. To foster the adoption of mobile technologies by SME in the AEC sector we have developed an implantation strategy as part of the research project called *IuK-System Bau*. The strategy provides a structured and user-oriented guideline concerning the introduction of mobile devices, wireless networks and mobile services into the individual company's specializations. This paper describes the various steps we have taken to develop the implantation strategy. One special focus of the paper concentrates on the presentation and analysis of the field tests conducted within our research project to evaluate the prototypes developed, namely the *Extended Construction Diary* and the *Mobile Errors and Omissions Management* application. The outcome of the field test has significantly determined the development of our implantation strategy.

1 INTRODUCTION

Recent papers have stated that the availability of mobile technologies such as mobile devices and wireless networks contributes to improved integration of field personnel into the electronic information flow of field personnel (Reinhardt et. al. 2002, Menzel et. al. (2003). However, the slow adoption of these technologies by SME shows that the availability of these modern technologies alone is not sufficient to close the gap in the information flow. Much more is needed to guide potential end-users of mobile technologies such as construction companies through the implantation process. Therefore, the authors have developed an all-embracing implantation strategy supporting end-users in their decisions concerning the implantation of mobile technologies into their businesses based on a detailed understanding of the related processes.

Currently, SME do not have adequate human and financial resources to test and implement mobile technologies within their organizations. However, SME are of big economical and societal importance in Europe. Therefore, the implantation strategy developed specifically focuses on the needs of SME in Architecture, Engineering, and Construction (AEC) and addresses the various aspects of the mobile computing paradigm in a holistic way. According to Rebolj (2001) the Mobile Computing paradigm is defined by three overlapping tiers: (1) mobile devices, (2) wireless networks and (3) mobile services.

Funded by the German Ministry of Research, Technology and Higher Education the authors have developed an implantation strategy of mobile technologies for SME in the AEC sector. The strategy efficiently and systematically enables SME to implant mobile technologies into their businesses by analyzing and re-engineering their business cases.

In this way, SME can compensate the disadvantages such as: (1) lack of up-to-date information, (2) delayed integration and validation of collected data, and (3) additional effort to collect and manage data. In the long run this enables SME to improve their organizational and working patterns, strengthen their market competitiveness and increase the qualification profile of their employees.

The implantation strategy was developed as part of the *IuK-System Bau* research project. The strategy is based on the two reference processes activity documentation (construction diary) and management of errors and omissions.

The paper is structured into five sections. Section 2 defines the requirements for the development of the implantation strategy by analysing the characteristics and needs of SME. Section 3 describes the project background emphasising the results of process analysis and system design. Section 4 describes the field tests conducted. Finally, section 5 integrates the findings into the envisaged implantation strategy.

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2 REQUIREMENTS FOR SME

Small and medium-sized enterprises account for the majority of companies in the European AEC sector. About 97 % of all companies in that sector have less than 20 employees and 93 % less than 10 employees, in FIEC (2005). They employ the highest percentage of people, and they generate about 82 % of the turnover in that sector, in Günterberg (2004).

However, SME are much slower in taking up new information technologies, respectively mobile technologies. But in today's time of e-Business, e-Commerce and e-Government the lack of appropriate IT-systems is a serious drawback for these companies, e. g. because contract participation requires electronic procurement and online submission, standardized data exchange, project communication and project information spaces.

The slow adoption of new technologies is due to the tight human and financial resources that do not have the capability to test and implement mobile technologies, in Günterberg (2004). In addition, SME are under-represented within the national and European research funding.

According to the European research rules and guidelines SME are defined as enterprises with fewer than 250 persons and an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million, in EU (2003).

However, SME are very diverse. Therefore, the authors have conducted several end-user workshops during the IuK-project with construction companies, service and technology providers to discuss the potentials of mobile technologies in the AEC sector. During the workshops end-user requirements for mobile technologies were defined, and a realistic picture of the situation of today's SME was obtained.

The authors identified the following main characteristics:

- different level of adoption of information technology,
- heterogeneous proprietary software systems, lacking open data exchange standards or only equipped with a minimal standardized interface,
- limited electronic standardized data exchange,
- different roles (as general or sub contractor),
- flat organizational hierarchies (typically one employee holds multiple roles),
- concentration on day-to-day business with a limited budget for research and IT.

The proposed mobile solution (including the implantation strategy) should be flexible and easy to configurate to meet the particular requirements of a certain company. The following major system features were identified:

- platform independence and integration need into available IT-infrastructure,
- integrated system for all project contractors and mobile remote access to the system (on-/offline),
- use of commercially available mobile devices and network types,
- standardized interfaces to proprietary systems,
- modularity and context adaptation.

3 PROJECT BACKGROUND

The proposed implementation methodology was developed in fulfillment of the *IuK-System Bau* project, which has been funded by the German Ministry of Research, Technology and Higher Education since June 2002. The funding aimed at the investigation and development of mobile solutions for controlling and documentation of construction site processes in SME. Two research institutes and two construction companies were involved in the project. The industry partners provided the system requirements as well as the test cases and test beds. The project work was divided into four phases:

1. specification and analysis of basic technologies,
2. process and requirement analysis,
3. system design and implementation, and
4. field testing, evaluation and set-up of implementation methodology.

Chapter 3 summarizes the results of the process analysis and system design, which were discussed in detail in Menzel et. al (2003) and Menzel et. al. (2004).

3.1 *Process analysis and potentials*

A profound understanding of relevant activities and their inter-relationships is needed to efficiently use and apply mobile technologies and solutions in practice. Furthermore, current management and process models need to be analyzed and re-engineered in order to fully exploit the potentials of mobile technologies.

Within the *IuK-System Bau* project two reference processes were analyzed, namely:

- the documentation process of construction activities resulting in the *Extended Construction Diary* application and
- the errors and omissions management processes resulting in the *Mobile E&O* application.

In the first step, the "as is" status of both processes was modeled - using the ARIS-methodology - and analyzed. Based on these models and in close co-operation with the construction companies (end-users) the processes were re-engineered and an optimized, general "as should be" model was developed. Different knowledge elicitation techniques were applied: interviews with employees of con-

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struction companies, intensive literature review (including technical guidelines, regulations, and recommendations).

Different types of process and data models (e.g. ARIS (with eEPK), UML, and ER-Models) were developed to illustrate and sustainably document the potentials of Mobile Computing applications. Potentials of mobile applications in construction may range from simply streamlining processes to the definition of complete new ways of working, including new organizational patterns, roles, and responsibilities, in Rebolj (2004).

3.1.1 *Extended construction diary*

Construction companies typically document their activities by using a construction diary which provides a summarized view of ongoing activities, occurrences, problems and circumstances at the construction site. It integrates information from other documents such as a list of drawings, a list of attendance or test records in compressed form. It is an important document of the companies' external reporting to the client or main contractor.

Currently, construction diary data is collected paper-based by construction managers or foremen on site. Additionally, it is necessary to collect data for other functional units using their specific forms (e. g. attendance list or material delivery list). So far, data collection is performed redundantly and parallel, but in different granularity and scope, leading to misunderstandings, failures and inefficient process patterns.

Therefore, the *Extended Construction Diary* application was developed to integrate different activities into one single process of data collection and documentation. In this way, the construction manager collects rhe data only once. By using mobile devices, data is immediately stored within an integrated information system. Nevertheless, each functional unit can access and analyze needed data and generate task-specific reports. The advantages of the new process and the mobile application are that data is collected only once but can be used multiple times according to the individual context.

During the development of the extended construction diary, considerable effort was exerted on the analysis of information and its classification as well as for the definition of context parameters, in Menzel et. al. (2003a).

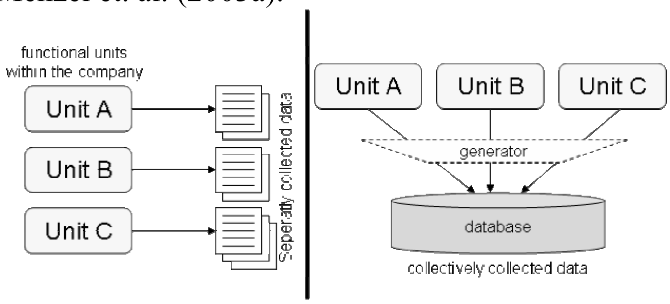

Figure 1: Different modes of data collecting at site

3.1.2 *Errors and omissions management*

The errors and omissions management (E&O) is a critical process for every construction company. Especially a short time before the hand-over of built artifacts, the number of errors can be very high, and the cost to for repairing them can increase in a short time. Therefore, a mobile, process-oriented software solution is needed, which can be used by most of the project participants.

The potential through the usage of mobile technologies arises from integrated data management, on-site data collection and immediate availability of information to all project participants, efficient data acquisition through the support of context-sensitive data acquisition techniques, and elimination of redundant data collection.

E&O processes were analyzed from different perspectives (as recommended in ARIS), namely: (1) the organizational perspective (actor), (2) the functional perspective (activities and events) and (3) the information perspective (documents and devices used).

As a result of the analysis phase it could be specified clearly who needs which information and where. Details of the analysis phase are described in Eisenblätter et. al. (2004) and Menzel et. al. (2004).

Figure 2 describes exemplarily one "shot" of the final process definition. As depicted in figure 2, many tasks such as data collection, forwarding, editing and attaching photos could be eliminated after the introduction of mobile applications.

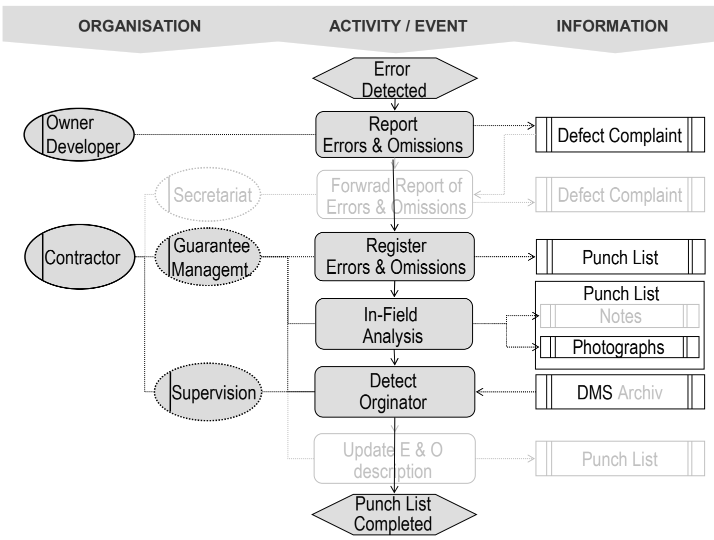

Figure 2: *E&O* Process.

3.2 *System design*

In the next step, single mobile applications need to be flexibly integrated into sophisticated information management systems. Existing IT-system need to be extended by the anticipated mobile business cases as defined during process analysis.

System design is based on the results from the requirement and process analysis (see chapter 2).

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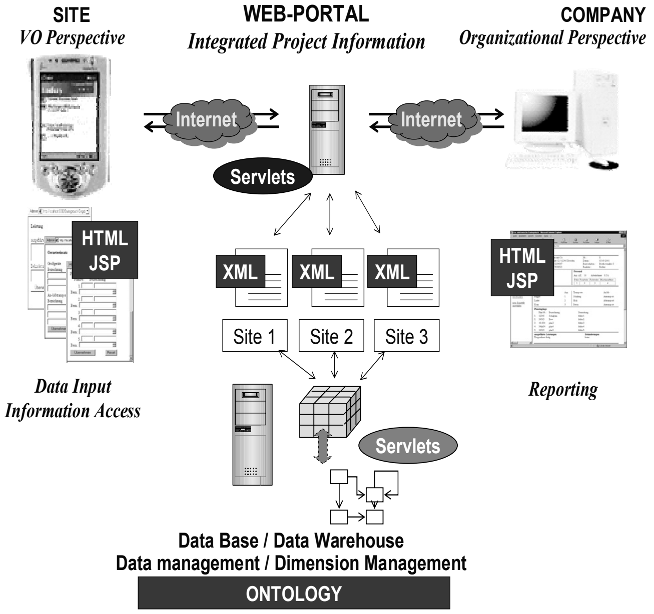

Figure 3: Infrastructure of the *IuK-System Bau*.

The system was designed as a web portal to allow easy integration into existing ERP-systems or to extend them. Access via mobile devices can be provided in online or offline mode through standardised interfaces ensuring secure data exchange.

Another design principle was to separate content from layout. This was achieved by using XML/XSLT technologies complemented by JSP.

Whenever possible, the system should work in online mode, securing up-to-date information and avoiding version or conflict management.

The user, working on construction sites, should be provided with context-sensitive services and information and not be overloaded with irrelevant information. Therefore, data is structured into applications, core data and classification data and managed in a multidimensional way by using the data warehouse paradigm.

Finally, the user shall not be hampered by inappropriate services and cumbersome in- and output techniques. Multi-modal interfaces were designed to address this requirement.

4 EVALUATION

4.1 *Evaluation goal and scope of field tests*

End-user involvement had a high priority in the *IuK-System Bau* project. The first prototypes were developed according to the principle of rapid prototyping and were tested in several field test cycles. The results of the field tests significantly determined the implantation strategy. The field tests were conducted to evaluate the functionality and usability of the software prototypes developed, including mobile devices and network types used.

The test methodology and test results are exemplarily described for test #1 (see table below).

Table 1: Overview of conducted field tests.

#	Type of site	No. of workers	Project costs	Company size	Region	Season
1	new building	~30	average	medium	city	Winter - Summer
2	renovation	~8	low	small	region	Winter
3	new building	~100	high	large	city	Winter

4.2 *Background of field test #1*

Field test #1 was performed on the construction site of the new building for the Department of Computer Science at the Dresden University of Technology. Construction activities started in autumn 2003 and are expected to be completed by autumn 2005. One of the project's industry partners was responsible as the general contractor (rough construction).

The construction site is situated in the southern part of the main campus of TUD. The building is a three-storey building with an underground floor. The building is composed of three main wings (west, middle and east wing) which are connected by so-called connectors. The wings are enclosing a glass-covered atrium and a u-shaped glass-covered foyer. The site covers an area of 100 m x 170 m. The foundation and the rough construction were constructed by one of the *IuK*-project partners. The tests of the mobile E&O management application were performed between January and August 2004.

During the rough construction phase a total of 7 companies were involved in the construction process. Approximately 3 or 4 companies were working at the site simultaneously. The industry partner of the *IuK-System Bau* project acted in the role of a general contractor by coordinating and controlling its sub contractors. The site is situated within the city and is covered by GPRS and UMTS networks.

4.3 *Field test organization and test methods used*

The evaluation phase was divided into three steps: (1) preparation of tests, (2) tests, and (3) analysis of test results. During the preparation phase a wireless network was installed and the devices were set up. Further, the overall evaluation criteria and the parameters to be observed (actor, device, network, location, task and time) were defined, see table 2.

Table 2: Instances of context parameters.

context parameter	instances
actor	foreman, construction manager, sales manager
device	PDA, rugged PDA, Tablet PC
network	GPRS; UMTS, W-LAN
location	in-house work, field work,
time (construction progress)	excavation, foundations, placement of formwork, reinforcement, concreted, replacing of formwork, finishing.

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Table 3: Tested combination of device and network type.

	MDA	Toughbook	Tablet PC
W-Lan	X	-	X
GPRS	X	X	-
UMTS	-	-	X

The intention was to evaluate the prototype in different situations (working contexts). Therefore, situations with combinations of several parameters in different contexts were defined, see table 3.

Strong efforts were dedicated to the preparation of the test personnel including: motivation, introductory seminars, preparation of tutorials and discussions during field-tests. Additionally, schedules were provided to the test personnel, specifying exactly the time when which device had to be tested and which task needed to be performed. Finally, an online questionnaire was prepared and was accessible as web-based application. The test persons were able to consult an assistant from the research group at any time during the test, who visited the site, answered question, downloaded and analyzed the results.

4.4 *Network tests*

4.4.1 *Goal and test method*

The network tests covered three different network types: (1) GSM/GPRS, (2) UMTS and (3) W-LAN based on the IEEE 802.11g standard. The goal of the network tests was to evaluate the availability and quality of service, installation efforts and operational costs for the company. Additionally, a special focus was placed on observing the change in availability and performance of the network due to the construction progress and the change of the building's shape. The results of the network tests will guide decision makers in construction companies in choosing which type of network is applicable in specific working situations. We have conducted two different network tests.

Test 1 intended to measure the relationship of signal strength and time to connect to the network as well as the response time of the web portal. The measurements were taken on site at 45 points weekly. Together with the technical parameters we documented time, weather conditions and battery status of the mobile device used. The construction progress was documented in sketches and photographs.

Test 2 intended to document the usability as experienced by the test personal while accessing the software prototype. The results were obtained through interviews and questionnaires.

In preparation of the field test each network type had to be made available at the site. GPRS and UMTS were available from different network providers. W-LAN required the installation of a hotspot at the site. Several alternatives were planned; figure 4 shows the final topology.

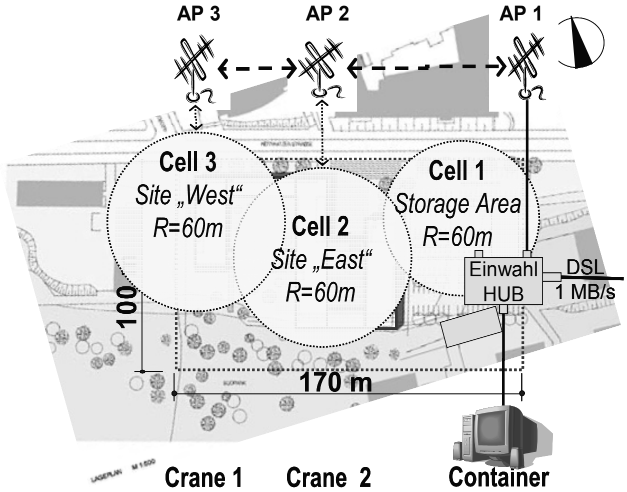

Figure 4: W-Lan topology with three APs at site.

The Internet access was provided by a DSL-connection (download with 1024 kbit/s, upload with 256 kbit/s) which was spread over the site area by three access points (AP). One AP was installed in one of the construction trailers, the two others were installed in the crane cabins. The installation of AP at the highest level of the site (see figure 4) assured network access at least at the top working-level during rough construction.

4.4.2 *Results*

The tests have proved that all three network types provided a sufficient download and upload speed for running the software modules. Table 4 summarizes the results for the different network types.

W-LAN networks have big discrepancies. On the one hand, W-LAN provides the fastest data transmission rate. On the other hand, it requires relatively high investment and maintenance efforts. Due to its dependence on electricity the reliability of W-LAN was less stable than the two other network types. Whenever the AP at the first crane was out of service, the other AP was affected because of the W-Lan bridge installed on crane 1.

While the costs for using GPRS or UMTS access can only be estimated, there is no cost for using the W-LAN in case of internal communication. However, the costs for the W-LAN are comprised of investment and costs for maintenance and operation.

Table 4: Comparison of different network types.

	WLAN	UMTS	GPRS
dialing-in time	very fast	fast	satisfying
site-build-up	very fast	fast	satisfying
network installation efforts	middle	low	low
device configuration efforts	low (only insert card)	low (only insert card)	minimal (GPRS is pre-installed on the device)
availability	good	very good	very good
costs	middle	very high	high

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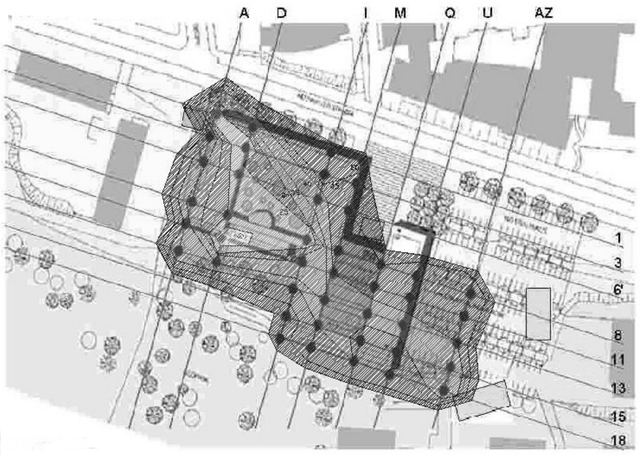

Figure 5: Iso-line representation of the LanCom Monitor-tool.

The authors predict that in case of intensive usage over a longer period of time W-LAN networks are more cost-efficient than GPRS or UMTS. The breaking point cannot be specified generally. It has to be determined on a project-specific basis.

During the comprehensive W-LAN tests we have measured varying signal strengths of between 20 % and 50 % with an average of 38 %. With a data transmission rate of about 11 MBit, the rate remained high constantly during the measurements, which confirmed the usability results of the test personnel. The W-LAN was the most preferred network type of the test personnel because of the fast response time.

The graphic representation of the signal strength (figure 5) shows that highest signal strength (darkest color) was achieved at the border of the construction site, while the center had the lowest values (lightest color). The reason was the location of the AP in the middle of the site at 15 m height and the directed transmission.

4.5 *Mobile device tests*

4.5.1 *Goal and test method*

The main goal was to evaluate the usability of different types of mobile devices for their usage on site. The following types of devices were tested: (1) Personal Digital Assistant (MDA III), (2) Rugged PDA (Panasonic Toughbook 18), and (3) Tablet PC (Fujitsu Siemens Stylistic ST 4110).

The tests were conducted in a two-step process. In the first step, technical paramenters such as processor type, clock frequency, storage capacity, battery type, display size, interaction means, operating system and built-in camera, were ranked by the test personnel according to the necessity for their work.

In the second step, the ergonomic criteria of each device were evaluated during usage: size and weight, functionality of the display, functionality of interaction devices and robustness of the device.

The focus of this test was on determining whether specific roles of an actor prefer a particular device.

4.5.2 *Results*

The PDA (type 1) received the highest appreciation from the test personnel. The rugged PDA (type 2) was evaluated as very attractive by foremen and construction personnel. In opposition, the Tablet PC (type 3) was evaluated as not suitable for usage on site by all test persons. Results summarized in table 5.

The weight and size of the PDA was very convenient for the test persons so that, in opposition to the rugged PDA, the test persons stated that it is no problem to carry the PDA the whole day. The advantages of the rugged PDA are its robustness and comfortable handling for hard-working personnel, e. g. by the carrying loop. The Tablet PC was evaluated as too heavy and bulky.

The displays of the PDA und the rugged PDA have only minimal differences and were ranked as ‘good’ by the test personnel. The small size of the displays was no restriction because the GUIs of the software modules were optimized to that size.

There was no problem using these devices in bright sunlight. The Tablet PC has a bigger display size; however, it was disqualified because it could not be used in sun light.

The preferred interaction mode for all devices was the pen in combination with the soft-keyboard. While there were no problem in using the keyboard with the PDA and the rugged PDA, usaging the keyboard of the Tablet PC was not as easy. The extra hard-keyboard on the rugged PDA was, unexpectedly, used rarely by the test personnel.

Table 5: Evaluation of mobile devices.

	MDA III	Toughbook 18	Stylistic
size, weight	+	0	-
display	+	+	+ / - (in sun)
interaction means	+	+	0
robustness	0	+	-

Legend: (+) good, (0) satisfying, (-) bad

4.6 *Software tests*

4.6.1 *Goal and test method*

According to the software evaluation approach proposed by Böhm (1981) and Balzert (1998) the prototype was evaluated in two tests.

The functionality test incrementally assessed the functionality of each single unit (graphic user interface). The test persons had to determine whether the provided functionality and data were appropriate and which were missing.

Business-process oriented test focuses on testing the application developed within a complete business-process sequence. Evaluation was performed by using usability criteria defined by the IsoMetrics technique. This technique provides a user-oriented, summative as well as formative approach to software evaluation on the basis of DIN EN ISO 9241,

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Part 10. The test covers the evaluation of suitability of task, software handling (controllability, learnability, conformity with user expectations), and software performance (error-tolerance, individualization and self-descriptiveness).

The evaluation of each item is assessed on a five point rating scale with a further ‘no-option’ to reduce arbitrary answers. The IsoMetrics design provides information that can be used within an iterative software development.

4.6.2 *Results*

Due to the incrementally conducted test of functionality the final prototype presented a well-balanced prototype.

The results of the business-process oriented test confirmed good usability of the overall prototype. The criteria suitability of task is an important indicator for the well-balanced design of the prototype which integrates and spanns over all aspects. The graphic user interfaces (GUI) and command sequences were evaluated as ‘good’. In some cases, the test personnel requested entering free text instead of choosing from a list of pre-defined text blocks.

Software handling was evaluated as diverse. Users requested improving the controllability criteria. They especially asked for less static GUI sequences. The conformity with user expectations criteria and learnability criteria were evaluated as ‘very good’.

The criteria in the category software performance were generally marked as good. Especially the error tolerance critieria received good marks because test personnel appreciated the highlighting of errors and adding advices. At the beginning of the tests, the prototype did not provide sufficient means for individualisation. Indeed, web applications typically do not provide many means for individualisation. One example for the requested individualization is the configuration of columns in *E&O*-reports.

5 SUMMARY

As one major result of the field tests an implantation strategy and related guidelines, especially focusing on the needs of SME, were developed.

5.1 *Scope and goal of the implantation strategy*

The implantation strategy aims at the provision of experience values and best practise cases to design and introduce mobile technologies in SME in the AEC sector. The strategy consolidates the results of the project, especially the findings of the field tests. Furthermore, it explains the prototypically developed web portal. The strategy is strongly end-user oriented with the intention to serve as a systematic decision base for company owners of SME.

The strategy is structered into three categories: (1) mobile devices, (2) wireless networks, and (3) mobile services. Each category is described by relevant criteria and their interrelationship. The categories and criteria relate to the context parameters defined in Menzel et. al. (2004). Criteria are structured hierarchically and have functional dependencies. Most relevant criteria in each category summarized in the following sub-chapters. For example, there is functional dependence between the availability of network and mode of operation because, whenever there is no network available, the mode ‘offline’ is the only one available.

5.2 *Categories of network types*

The availability of a wireless network connection is a pre-requisite for the usage of mobile online services on site. Therefore, the availability of a network is a knock-out criterion. Relevant context parameters are the location and the application (amount of data).

Further selection should be based upon the following criteria stated in table 6.

W-LAN might be the suitable network type in long term projects or rural areas because of low operation costs, high bandwidth and independence of commercial mobile telecommunication networks (GPRS, UMTS). For shorter usage time periods and a small amount of data to be transmitted, GPRS or UMTS might be more economical.

Table 6: Evaluation criteria for network types.

network types														
technical criteria			quality of service						economical criteria			environm. criteria		
transmission rate	range of signal	etc.	signal strength	data flow rate	delay	reliability	dialing-in time	etc	investment costs	maintenance costs	operation costs	type of site	type of region	etc.

5.3 *Categories of mobile devices*

The selection of the appropriate mobile device is strongly influenced by the context parameters actor role (which determines the task and software module), personal preferences and location (weather conditions).

The category can be characterized by the criteria set in table 7. The most relevant criteria for field personnel are size and weight (easy to carry, convenient to handle) and display characteristics (usable in sunlight). Technical criteria were only of secondary interest; in particular, the different types of mobile devices do not significantly vary in their technical criteria. Robustness might be relevant for actors permanently working in the field.

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Table 7: Evaluation criteria for mobile devices.

Mobile devices	technical criteria	processor speed, storage capacity, number and type of interface slots and operating system
	display criteria	size, resolution, colors, quality
	navigational criteria	type, mode
	connectivity criteria	build-in communication protocols
	usability criteria	size, weight, robustness, temperature range, battery duration
	economical criteria	costs for investment, maintenance, operation (software licenses, etc.)
	functional criteria	data-voice-integration, document edition, personal information management appl.

The project defined following three types of mobile devices, see table 6.

Table 8: Types of mobile devices.

PDA/Smartphone	Rugged PDA	Tablet PC
classical PDA or Smartphone 	protected from dust, water and shocks, works in larger temperature range 	ability to flip the touch screen; 

5.4 *Categories of mobile services*

The category *Mobile Services* is the most complex category. It supports the user in the specification of the final end-user application and indirectly supports the underlying IT infrastructure. However, a thoughtful in-depth analysis of business processes and identification of re-engineering potentials including mobile use cases are pre-requisites.

The analysis should be structured along following 7 defined criteria as shown in figure 6.

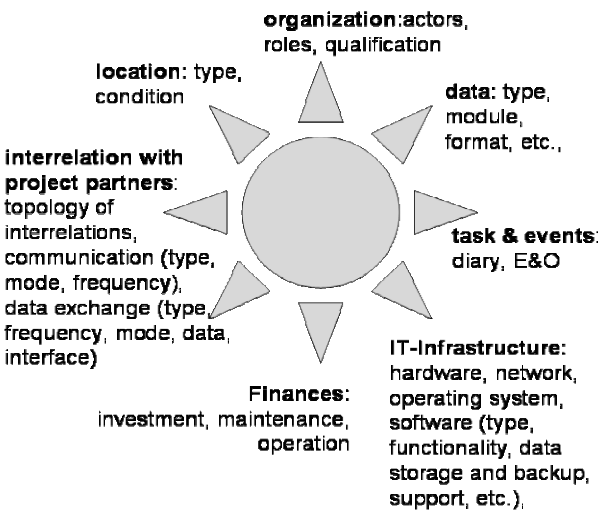

Figure 6: Evaluation criteria for category mobile services.

Exemplarily, specification of data is a major step. There the data available in the existing IT-system has to be described in terms of data type, mode, etc., as well as the data that needs to be exchanged. In the advent of *e-Business and virtual organization* communication and data exchange plays a major role, which requires interoperability of software systems by standardized interfaces and protocols in SME.

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