EFFECTIVE CONTROL OF UNANTICIPATED ON-SITE EVENTS: A PRAGMATIC, HUMAN-ORIENTED PROBLEM SOLVING APPROACH

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SUMMARY: *Unanticipated events on building sites are inevitable. The frequency of unanticipated events is usually high due to the inherent complexity and dynamics of construction projects. A proper mobile interactive personal network can make use of the rich knowledge and experience of site staff, to handle and effectively resolve on-site problems caused by unanticipated events. Immediate on-site problem solving significantly impacts subsequent project characteristics and leads to a more productive organizational processes as a whole. This paper focuses on the importance of interactive personal communication as a basis for immediate on-site problem solving. For communications support, a human-oriented pragmatic solution in the form of a mobile, interactive, context-sensitive personal network is presented.*

KEYWORDS: *mobile computing, problem solving, construction site, rapid communication*

1. INTRODUCTION

On-site construction operations require complex coordination between a number of activities. Effective construction processes depend on good synchronization of materials delivery, movement of equipment and construction tasks. Coordination tasks are often complicated by schedule pressure and productivity demands, worker fatigue, data loss during information exchange, misunderstandings because of poorly defined information, and iterative negotiation when unanticipated events occur. Moreover, every change in activity context, costs, requirements, deadlines, etc., can modify important project characteristics, which in turn indicates a high risk for possible discordance of activities. This requires an improved networked thinking that brings partners to closer interaction. However, without appropriate computing support this may increase the difficulty of problem solving.

It is a common misunderstanding that computers are of little help at a building site, due to the predominantly physical nature of on-site operation. Actually, construction work requires careful planning and skilful management of human and physical resources. Computer systems can assist on-site staff to plan ahead, evaluate different options, adopt and execute the most efficient construction operations, and solve unanticipated problems.

In the field of civil engineering, interesting reports can be found for mobile computing applications that assist on-site processes, such as inspection-oriented applications (Garrett and Sunkpho, 2000), navigation through drawings (Reinhardt and Scherer, 2000), on-site project document queries using digital measurement tools and synchronization (Hernandez, 2000), web-based punch-list-like application (Menzel et. al., 2002), pilling operations (Ward et. al., 2002), mobile sensoring (Delsing and Lindgren, 2003), video mediated teamwork (Johanson Törlind, 2003).

Most mobile computing applications are specialized for a specific task. They can be divided into the following groups (ARUP, 2003):

- *Data Capture*: tools for specific applications such as Time Sheets or Inspections and component-based software or services for the creation of one's own business applications for mobile computing.
- *Technical drawings*: production of drawings for use in the field. Although the drawings are produced electronically, they are printed out for use, which eliminates many of the advantages of their electronic nature, and reduces the opportunities for effective feedback.
- *Project Management*: The project administration area overlaps with some of the features that collaboration tools offer. However, there are also software applications available that extend existing desktop computer software for use on the field.
- *Collaboration Software*: Currently, there is a great deal of discussion about web based collaboration systems solving the industries fragmentation problems. However, these systems are not yet in common use in the field by foremen and site engineers. Therefore, the flow of electronic information is disconnected when it reaches the construction site. In turn, many of the benefits based on efficient process organization and existing knowledge and expertise are lost. Collaboration Software suppliers are beginning to address this issue by extending key collaboration features to mobile users in the field, either through mobile phones or other handheld devices.

Although communication and collaboration tools recently became more attractive with the success of the Internet, little effort has been done to support mobile on-site problem solving. According to experiences from a series of experimental projects called E-site, it is our strong belief that a large amount of potentials for on-site problem solving lies in the knowledge and experience of the site staff itself. Therefore, there is a need to effectively link together project management and site staff, and include site staff into problem solving processes by handling unanticipated events on building sites where quick and correct decisions are required. We suggest an *approach based on mobile interactive context-sensitive personal communication* to help dealing with unanticipated events on building sites.

2. THE E-SITE EXPERIENCE

In autumn 2000, a multipurpose, experimental, educational research project called Mobile Computing at a Construction Site (shortened "E-site") was launched at the Faculty of Civil Engineering of the University of Maribor (Rebolj et al., 2001). The project was conducted by the Construction IT Centre and carried out by students and engineers from the construction industry. The purpose of the project was to answer the open questions of how mobile computing works on sites, which organizational changes are required, whether the common commercial mobile phone network services are sufficient for mobile computing in construction, to determine the complexity of the problem of integrating mobile computing into existing information systems (which are still not integrated to the desired extent themselves), and to identify necessary educational efforts.

FIG. 1: E-site, an experimental and educational research project

The final test of 2001 (Fig. 1), showed, that the efficiency of information exchange in construction, between the construction participants and within the construction site itself, can be improved significantly even by using

current mobile computing components: unmodified, available PDAs, mobile phones and other existing wireless networks, and internet services. This project was continued in 2002 (Magdič et. al., 2002), when we designed a mobile document management system to support a more effective on-site document exchange.

A basic data flow diagram was elaborated (Fig. 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.

Microsoft platform (Windows IIS Server, Windows CE), wireless communication (GSM, WLAN) and mobile devices (PDA) were used for setting up the mobile document management system. On-site users logged through client application to the remote host (data server) using telnet protocol and transfer of documents (files) was achieved through File Transfer Protocol (FTP). Server information was provided through member's password access right's. As change in projects file structure occured members of the project team were notified automatically through email or SMS message.

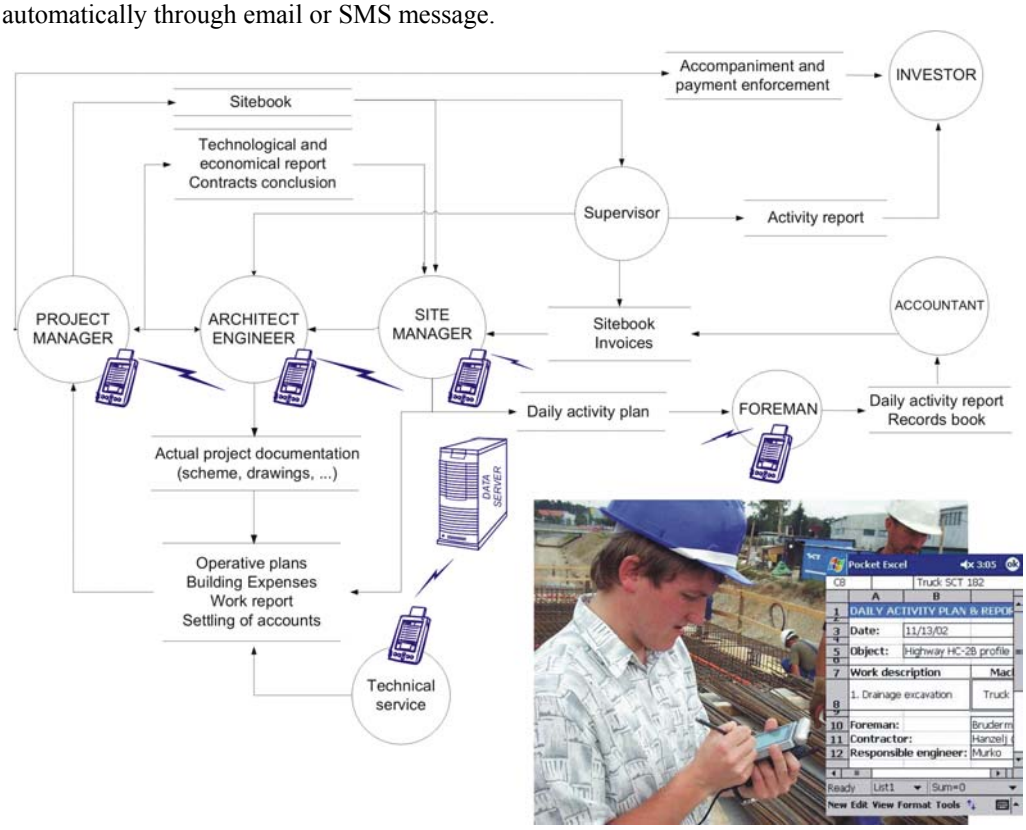


FIG. 2: On-site document exchange supported with mobile computing

In the 2003 E-site project cycle, we started more detailed research on on-site interpersonal communication characteristics by solving specific problems caused by unanticipated events.

Our basic assumption was that experienced site staff can significantly impact effective on-site problem solving. In experiment we observed on-site interpersonal communication according to the already elaborated on-site information exchange (Figure 2). In case of solving specific problem it was evident that all involved persons were experienced workers. Instead of formal, specified communication, they used informal communication to effectively solve the problem. Detected problem examples caused by unanticipated events are shown in Figure 3.

Our findings only confirmed our assumption that, to a certain level in the organizational hierarchy, some needed information is not available to most participants, despite the necessity of fast and effective exchange of information between a construction site, investors, headquarters and all other involved parties.

Often, just open and direct project-wide communication is what contributes to the project's success, enabling all participants to be permanently, actively involved. In such cases, when dealing with a specific on-site problem, the foreman should be able to contact not only the site engineer, but also the other partners, including designers,

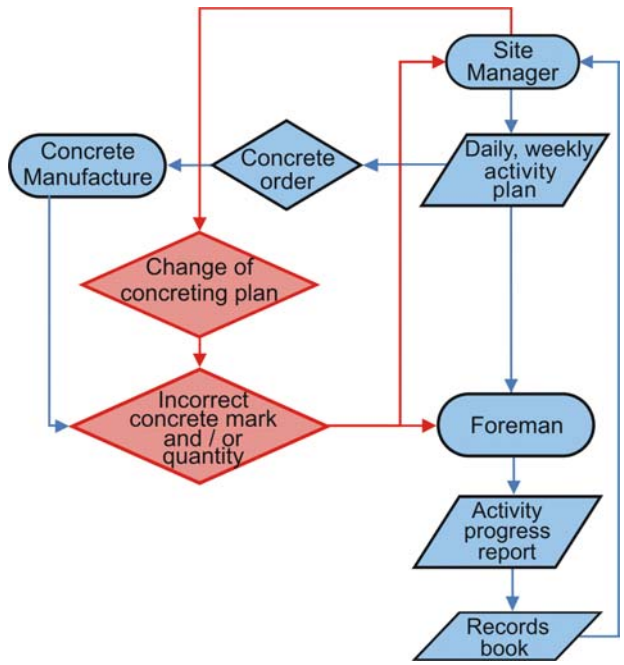
planning engineers, R&D specialists, the supplies department, etc., according to the nature of a problem.

Based on our interpersonal communication research findings, we propose an interactive personal communication network, as described in Section 4, to effectively combine information, experience, and competence for the purpose of solving specific problems caused by unanticipated events.

3. ON-SITE INTERACTIVE PERSONAL COMMUNICATION

3.1 Solving on-site problems caused by unanticipated events

As we have stated in the introduction chapter, unanticipated events, which take place due to the particular nature of construction projects (dislocation, uniqueness, multidisciplinarity), can significantly impact costs, completion deadlines, process organization, etc. and jeopardize the project realization. Although unanticipated events can not be prevented, they can be managed effectively. Fig. 3 shows some unanticipated situations. Every on-site activity is performed according to the daily or weekly activity's plan which concludes with activity progress report and noting in records book. Detailed activity plan and project drawings contains data for material order. To assure material timely suppliers receive order before material is needed. Problem occure when due to the unanticipated events already delivered material is incorrect. In case of concreting activity due to the unanticipated events (weather conditions, unsuitable equipment, etc.) site manager need to change concreting plan. Foreman perceived a problem with already delivered concrete mark and / or quantity. Quick solution is needed, foreman and / or site manager need to interact mutual, with other project members on near construction sites which are appropriate to use delivered concerete, etc.



Unanticipated situation in concreting activity

Other problem examples:

1. Material handling
- incorrect, improper material delivery, delivery delays

2. Equipment movement
- unpreprared (e.g. panells), unsuitable equipment

3. Building work
- details realization (insufficient design, changes during construction phase)
- personal aspects (human factor)
  - interpersonal communication failure, problem misunderstanding
  - weak workers motivation and activity
  - insufficient informing

FIG. 3: Unanticipated situations - problem examples

For the effective solving of such problems, the immediate availability of information and a prompt response of project participants on various levels of project organization are crucial. The combination of the two facilitates the optimum decision-making in cases of critical (unanticipated) events. Problems are solved concurrently and where necessary, relying on the individual and his knowledge and capability. Also, effective interpersonal communication is crucial for swift (simultaneous) sharing of information.
Interactive personal communication in the problem solving process on the construction site, as well as in general, is based primarily on experience-based solutions (experience and knowledge of individuals), and only secondarily on technical support in the form of plans and other documentation. This approach favors the personal

aspect and is user- or human-centered. Technical support, is of utmost importance in cases, where the chosen solution must be documented and archived (in cases of plan detail changes, work plan changes, etc.). Interactive personal communication also carries a motivation value in the sense of the individual's feeling of belonging to a team, where he is seen as necessary and important.

3.2 Novel decision and organizational structure

Interactive personal communication means a direct and open channel of communication, which shows additional benefits in cases where problems must be solved instantaneously. Existing project organization schemes are ineffective in such cases, and their lack of efficiency shows the need for their transformation in the sense of facilitating an increased capability of simultaneous participant responsiveness (Fig. 4).

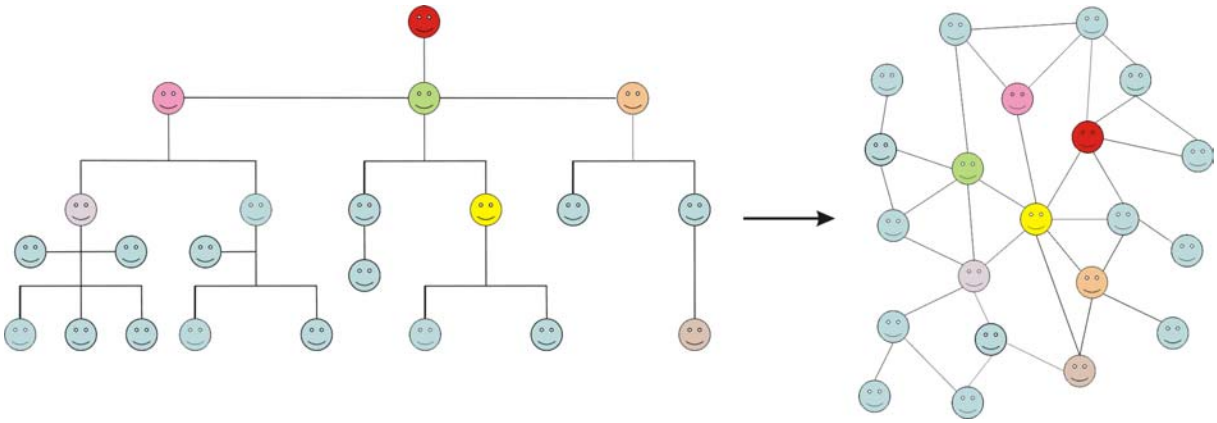


FIG. 4: Hierarchy transformation, from static to dynamic structure

In the project organizational structure, the chain of command or information gathering is inherently hierarchical. The hierarchical status determines the roll and authority of the individual subject, which is the main reason for the lack of effectiveness continuous on-site problem solving in the construction process and on the higher project level.

Our further activity within E-site research project is to optimise decision processes, and through the change of the decision model to develop an essentially optimised generic organisational model. The model is based on the core belief that all participants are to utilize the potential of mobile information access. In the frame of the created model, we will also define the responsibilities, authorities, and competencies of individual participants. They will not be specifically detailed, as they are not included in the framework of this paper.

In this way, decisions are also made on lower hierarchical levels or on levels in the organisational structure where they are necessary. The multilevel organizational structure effectively becomes a network structure, and the problem solving process is accelerated and more effective.

3.3 Interactive Personal Communication Network - IPCN

Transformed multilevel organizational structure brings project partners and participating individuals to closer interaction. They are “connected” in such a way, that their immediate reactions are made possible. Each group participant, especially from other project groups (e.g. other building site, external project partners, headquarters, can help resolve the problem. In this way, they form the interactive personal communication network (Fig. 5).

The key benefit of the interactive personal communication network lies in the collective problem solving using the current knowledge and experience of partaking individuals, as well as the immediate access to necessary information.

Inadvertently, we are imparted with the mobile telephony image, which is a great benefit in the construction field. The widespread use of mobile phones made it possible to reach nearly any actor in any process at any time, thus providing significant support for an undisturbed flow of information. Unfortunately, in such a case the level of process automation is actually nil, but at least distance is not such a problem any more.

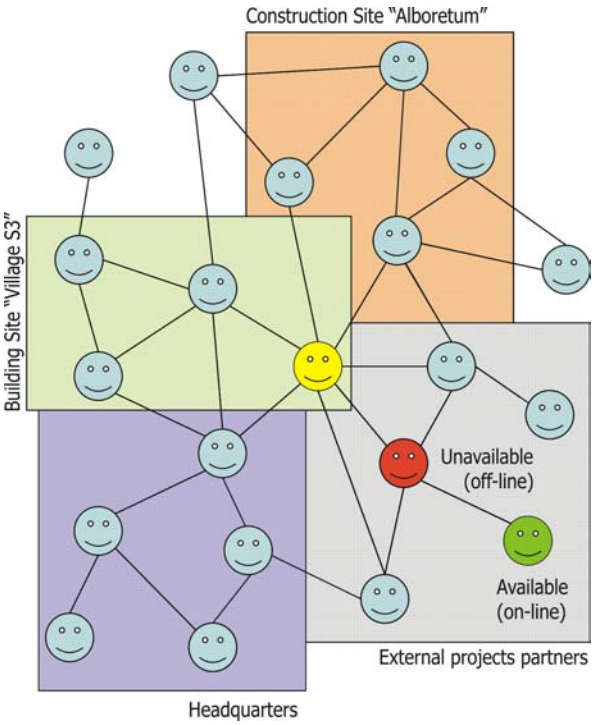


FIG. 5: Interactive Personal Communication Network (IPCN)

Still the IPCN is a fundamentally different, and primarily dynamic network. Its core characteristics include:

- Always online (in terms of personal communication and document availability)
- The combination of various types of communication and information exchange in various formats (text, raster and vector graphics),
- Contextual sensitivity

From the functionality aspect, IPCN provides the right (necessary) information at the right time, in the right place:

- Instant availability of process information from the construction site (activity progress reports, delays, problem descriptions etc.).
- Building ad-hoc mobile teams for joint problem solving and coordination to resolve an issue.
- People in the field can work "closer" to each other in terms of more direct and open communication. Due to the more open communication, organizational hierarchies become structured on a single networked level (flattened).

The key assumption of the presented network is the construction site personnel equipped with mobile computers (such as PDA, tablet computers, …). The site features a wireless network connection, which serves the communication (information flow) on the site, as well as the connection to the servers hosting services and data (Fig. 6).

In the case of an unanticipated event, the competent person ("on-line helper"), with the help of the mobile device and suitable software support, acts with a quick solution. Before final measure of "solution searcher" is taken, solution is decided on in a joint effort with the other on-line project participants. The "solution searcher" only contacts those, who are available (on-line) and suitable for the assistance of solving a particular problem. The options include persons on the same site, location, in the frame of the same project, etc.

Because the individual in the organization is usually participating in several projects, the contextual sensitivity of the communication system is vital. Another important task is the connection to existing project and organization schemes, as well as providing a simple, clear, and possibly multipurpose user interface. One of the promising solutions is the integration of a personal calendar on mobile device and a project management environment (Fig. 7). The personal calendar data (time, activity, etc.), settings of the mobile device (user account, password,

availability, etc.) and location information retrived from sensors on or connected to the mobile device can be adapted to each individual's work context.

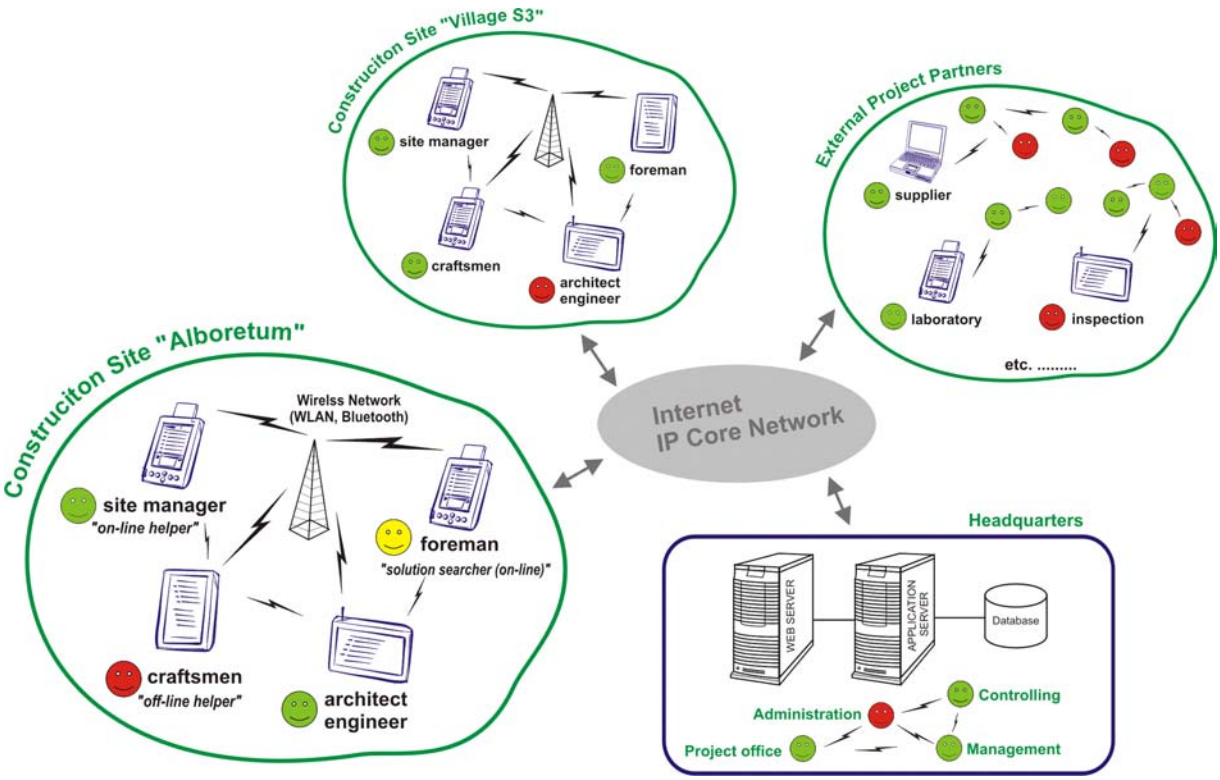


FIG. 6: Interactive Personal Communication on a Construction Site

There are various contexts to an individual's work, the most important one being the one that connects the momentary activity with the suitable subgroup of persons. The context in this case is the project or an individual activity within the project. Therefore, the communication system ensures that in the case of an individual activity, only those persons that are directly connected to the activity in question are "nearby". On request, the context can be expanded in the desired direction, which means persons, who are in a way connected to the activity. For example, in cases of concrete molding, only persons connected to concrete molding are displayed, or perhaps all persons involved in the project, etc.

The software infrastructure of presented network consist of server and client software modules that interact each other to ensure context aware delivery of project information from the servers to the mobile device (Figure 7). The modules exchange information in form of XML (eXtensible Markup Language) tuples which represent a list of data fields expressed in XML. XML is essentially text based, it can integrate easily with existing application and provides an encoding mechanism for sharing information and functionality between disparate systems. For communication between the clients, the network (web) services and the main server is used Simple Object Access Protocol (SOAP).

Based on the type of the information they provide different web services (context, data, processing services) are accessed through HTTP and described using XML Web Service Description Language. To reduce the communication requirement and to help deal with the interuptions in the wirelss connectivity list of capabilities and requirements of all web services available to the users is stored and synhronized between server and mobile device.

Context description module on mobile device is responsible for building individual's work context description. After querying sensors for the information that defines raw context (time, position, orientation, availability and quality of the internet connection, etc.) its objective is to refine the context using available local or network services (web services). For example a context service would take in the values of online availability to provide online contacts associated with current project or data services can search and retrive specific set of documents

from the server. The context description module then iterates invoking available services until it detects that the iteration did not produce any changes to the context.

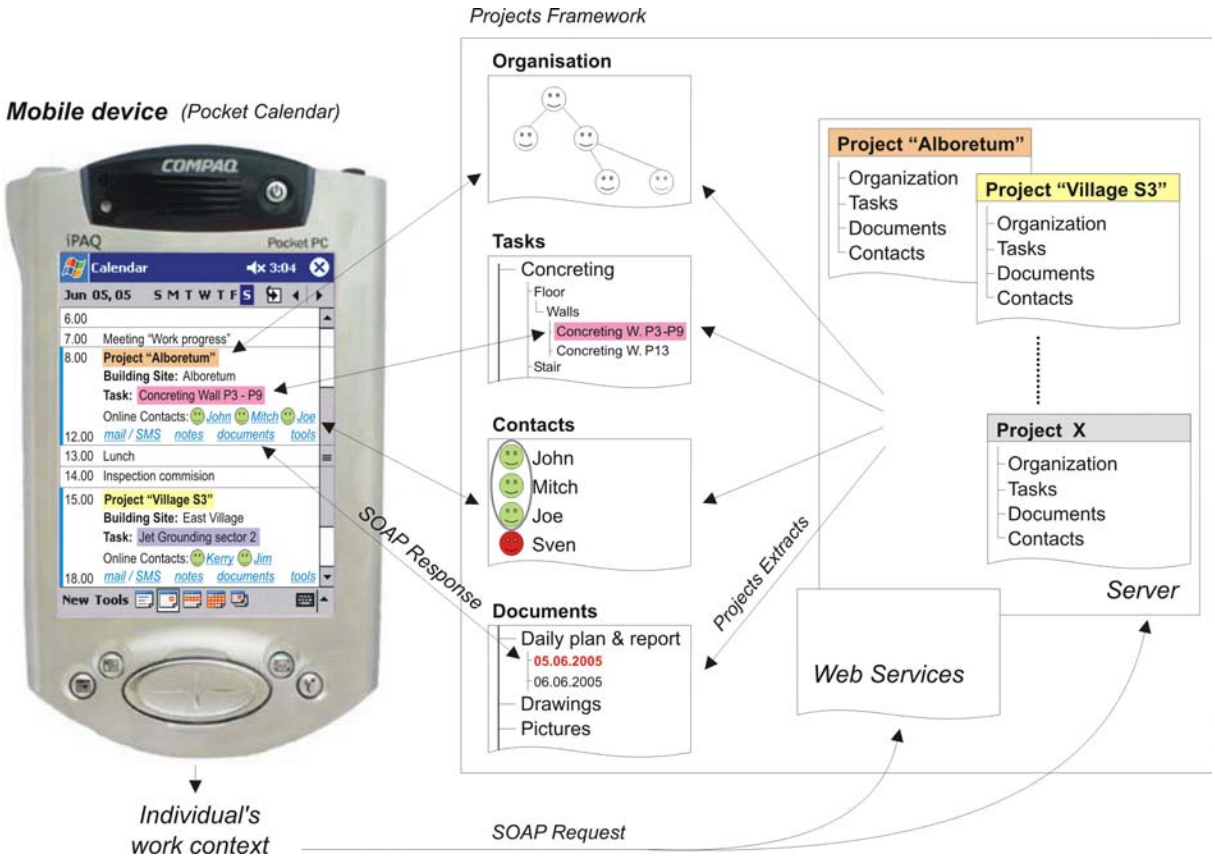


FIG. 7: Schematics of an IPCN

4. DISCUSSION AND CONCLUSION

The solution of daily problems in the construction process significantly affects the building and general project process, due to unanticipated events.

The paper has shown that interactive personal communication is the basis on which such problems are solved. The continuous process of problem solving is most effective if it relies on the connection of persons, who communicate on a single-level (decentralized) communication network, supported by mobile computing. The mobile interactive personal communication network represents a group-based problem solving process on various levels of the organization structure with direct (current) use of the knowledge and experience of individuals.

The recommended solution with the systematic use of the technology of mobile computing offers several advantages:

- *Problem solving speed (time saving) -> crisis prevention:*
  With the use of mobile computing technologies, the geographical (physical) distance becomes a neglectable factor in the cooperation of relevant persons, which has a profound effect on time saving.
- *Solution effectiveness -> better quality -> lower costs*
  The solution effectiveness is increased, because this work process offers the ease and transparency of supervision.
- *Information control*
  All submitted and received information and data is saved, which enables their immediate use and subsequent control.

We must consider the limiting factors as well though:

- *Additional education*
  Every introduction of new technology requires additional education. In this case, it is vital, that future users are familiar and well informed about the benefits of modern technology. Only in this way they can become regular users of the system.
  On the other hand, when trying to make use of all the potentials of mobile and ubiquitous computing, the existing concept of computer use is a fundamental problem.
  Most of existing applications are connected with some kind of e-commerce, despite the fact that engineering applications were one of the first and most important driving forces that commenced computer use from the beginning. Unfortunately, nowadays many engineers are still using tools that are far from state of the art and are becoming very reluctant to changes.
  In the past few years, we encountered increasing gap between research in information technology and state of the practice of everyday engineering work. Here we are facing a paradox. Engineers - people with strong technical background - refuse advances in technology. We see sources to this situation in complexity of engineering information structures and existing processes that should be changed to support the new.
  If mobile and ubiquitous computing should bring new value to engineering process, we should rethink current philosophy of computer use of today. As a consequence, we expect processes to become of a higher quality and more productive.
- *New technology investment and added equipment purchase costs*
  The investment into this technology and equipment purchase represents a large investment, which may be out of reach for many companies.
- *Accessibility of participants*
  For a successful (current) problem solving, as many competent people as possible must be available.

Our further challenge is to actualize the discussed approach and apply it to a present on-site process. To achieve real implementation, a prototype will be built in collaboration with our partners from the construction industry.

5. ACKNOWLEDGEMENT

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