Socio-technical management of collaborative mobile computing in construction

A. Löfgren
Department of Industrial Economics and Management, Royal Institute of Technology (KTH), Sweden

ABSTRACT: The constant changes of plan and unanticipated events in the production process at construction sites result in communication patterns that are dynamic, spontaneous and informal. Most of the existing ICT tools do not sufficiently support informal communication for powerful collaborative problem-solving, management of site resources, handling of parallel process activities and do not correspond to the basic needs and work patterns at the construction sites. Mobile computing technologies have the potential to provide an inclusive wireless mobile ICT platform (voice and data) that can enable improved support for informal communication and on-demand data at construction sites, which can result in improved project collaboration leading to increased efficiency and productivity in the construction process. Still, an implementation strategy for collaborative mobile computing at construction sites is complex and must consider numerous issues regarding system capabilities, mobility, applications, services, integration of existing ICT systems, user interface and user devices to meet the requirements and behaviors of site workers in the mobile distributed heterogeneous construction environment. A mobile computing platform needs to be designed, implemented and managed with a socio-technical bottom-up approach realizing end user and group needs, understanding the separate issues of adoption on different organizational levels, and recognizing mobile computing as a process integrated enabling technology for improving collaboration and project communication throughout the whole construction process.

1 INTRODUCTION

It is widely known that since the boom of the personal computer and the Internet, companies and industries have experienced increased efficiency and productivity through the use of Information and Communication Technology (ICT). In the construction industry much effort has been made to improve processes with the help of ICT, but the industry has not achieved increased productivity to the same extent as others. Samuelson (2003) shows that while the utilization of ICT was high in the design phase and in facility management, the use of ICT by contractors and site workers in the construction process is surprisingly low. Part of the poor productivity figures in the construction industry could be explained by the fact that the information needs and communication behaviors in the production at the construction sites are not adequately met. Most of the available project oriented ICT tools are meant for formalized "white-collar" office use. These tools give modest support to the craftsman-like construction activities and the unpredictable, dynamic, spontaneous and mobile environment that the "blue-collar" site workers work in. Improving ICT support for the core activities at construction sites and for site workers' information and communication needs is a strategic challenge for the construction industry to increase efficiency and productivity in the construction process (Samuelson, 2003).

The construction site can be described as a reactive environment, where unplanned changes to work regularly occur (Ward et al., 2004). Unanticipated events and temporary critical problems are in this environment inevitable. The high frequency of unanticipated problem situations at construction sites is due to the inherent complexity and dynamics of construction projects (Magdič et al., 2004). Construction activities are dispersed and site locations frequently change, which is problematic when giving construction sites sufficient ICT support. The required ICT infrastructure is often deployed to the site office, but rarely reaches the construction site itself (Čuš Babič et al., 2003). De la Garza & Howitt (1998) observed that the main communication issue in construction is to provide a method to exchange data between the site operations and the site office. The communication requirement in the construction process can vary from off-site to on-site communications (Kuladinithi et al., 2003). Example of off-site communication requirement is the need to connect to networks of suppliers and other related organizations participating in the project. On-site communication requirements involve the direct communication between project participants at the construction site.

Quality, quantity, and timing of information are the three fundamental variables which can either hinder or facilitate successful results in a construction project (De la Garza & Howitt, 1998). As much of the administrative tasks at a construction site are still paper based, this delays the flow of data and the available information may become obsolete or insufficient. In addition, low efficiency occurs because of the gap in time and space between the paper based administrative tasks at the site and the subsequent computer work back at the office (Kimoto et al., 2005). A shift to a complete ICT-based exchange of information can improve the timely instant delivery, access and computing of information (De la Garza & Howitt, 1998). Innovative implementation and use of ICT can also enable businesses to structure and coordinate activities in ways that were not possible before, leading to new strategic advantages (Attaran, 2004).

Aouad et al. (1999) observe that during the last decade of the 20th century the construction industry has started a technological shift from ICT driven solutions to ICT enabling ones. However, the industry has become frustrated with the failing of ICT as many companies have invested in the wrong technologies without addressing business needs. Another aspect that complicates this picture is that the involved participants in a construction project typically are at disparate levels of organization and ICT use. Therefore, they are forced to use mutual project oriented ICT tools at a very low level of integration (Čuš Babič et al., 2003).

In recent years the construction industry has moved towards Internet based collaboration and project management systems, hoping to solve the fragmentation problems of construction projects and allowing project participants to get more involved at the early stages of a project. These collaborative working solutions are tailored primarily towards the needs of desktop-based fixed computers. The consequence of this is that the flow of electronic information typically reaches selected personnel in the site office (Bowden & Thorpe, 2002), leaving collaborative information and communication needs of mobile site workers inadequately addressed (Aziz et al., 2004). Many of the efficiency and knowledge-based benefits of the collaboration tools are therefore lost. Developing and extending ICT-based collaboration and project management tools to include information and communication needs at construction sites is an essential factor in eliminating these problems.

Much of the inefficiencies at construction sites arise from interruptions between activities and processes as well as delays within individual operations. These interruptions are often a result of poor planning, insufficient information and supply-chain problems (Boussabaine et al., 1999). A site based ICT platform that enhances coordination, communication and provides quick access to relevant data could reduce many of the common on-site delays present today.

The development of wireless and mobile technologies is progressing rapidly. Over the past ten years wireless networks have increased their speed more than tenfold which allows for more useful and compelling mobile computing applications and services. Similarly, the cost of handheld computing devices has plunged and their performance and user interfaces have improved. Therefore mobile computing has become a consideration for many enterprises and industries. It is believed that mobile computing has the potential of providing solutions to the ICT issues at construction sites and enabling better use of knowledge and experience of site staff to effectively handle on-site problems caused by unanticipated events (Magdič et al., 2004).

However, designing, implementing and managing a mobile computing platform in a mobile geographically distributed and heterogeneous construction project is far from trivial. This paper reflects upon some of the socio-technical collaborative aspects of mobile computing in construction. A Socio-Technical Systems (STS) perspective on technology management is the starting point for the analysis. This STS perspective focuses on the design of work for both organizational and human good and how the complex interactions between people, organizations and technology should be arranged to enhance the quality of work (Griffith & Dougherty, 2002). One of the aims of the STS perspective is to provide insights for understanding the relationships between people, technology and organizational outcomes (Griffith & Dougherty, 2002). In this paper the main argument is that a user oriented bottom-up approach is needed to succeed in adopting mobile computing in the construction industry. The purpose of the paper is to outline a schematic framework of the broad socio-technical issues of mobile computing at different organizational levels of a construction project. This can serve as a suggestion for further research in the topic of managing the technological and organizational collaborative aspects of mobile computing in construction.

2 THE ROLE OF INFORMAL COMMUNICATION IN COLLABORATIVE WORK

Informal communication plays an important role in handling unanticipated events and solving critical problems. Informal communication is not a planned activity with a set agenda or fixed location. It occurs spontaneously, almost everywhere and has a large impact on work processes and outcomes that can be even greater than formal communication (Johansson & Törlind, 2004). The spontaneous interactions in informal communication enable frequent and instant exchange of useful information resulting in issues being discussed and resolved as they occur, instead waiting for a suitable and scheduled time to make a formal decision (Johansson & Törlind, 2004). The nature of formal communication, on the other hand, is that it tends to be used for coordinating relatively routine transactions within groups and organizations (Kraut et al., 1990).

Informal communication supports organizational and group coordination, especially under conditions of uncertainty. It helps members of a group in learning about each other and understanding their work. Informal communication supports both the actual production and the social relations that underlie the work, and is a critical activity to initiate collaboration, maintain it, and drive it to a common goal (Kraut et al., 1990). Informal interactions are also important in getting people to know and like each other to create a common context and perspective to achieve better planning and coordination in group work. Collaboration is less likely to start and becomes less productive if informal communication does not occur (Kraut et al., 1990).

Informal communication is distance sensitive and happens most often between people who are physically close to each other (Kraut et al., 1990). Designing ICT systems that enable better support to informal interactions in dispersed organizations is a great challenge. It is difficult to overcome the distance between the space where a person is located and the space where some valuable source of information or another person is placed. Rebolj et al. (2004) argue that it is essential to shorten the distance between the real world and the virtual space to achieve efficient mobile computing. Physical distances in the real world are often expected to be reduced by the use of ICT, but the fact is that many ICT systems actually introduce a new distance in the virtual space instead. Systems that do not create the "virtual shortcut" that improve the flow of information or enable better support for interpersonal communication, make communication even more complicated.

Kraut et al. (1990) note that the more spontaneous and informal communication is, the less it is supported by information technology. ICT systems must hold special requirements to efficiently support informal interaction between people at physical distance (Kraut et al., 1990). For example, the group of people that are working together have to be connected to the same network and must be easy to get in touch with. For informal interaction to occur, people need an environmental mechanism that brings them together in the same place at the same time. Tools that inform who is online, where persons are physically located and their current activities are important in this aspect. The personal cost of communication, the effort needed to initiate and conduct a conversation, has to be low. It is therefore necessary that a system enables contacts with other persons as easy as bumping into each other in the hallway. The visual channel of a system plays an important role for informal communication. The visual channel provides a means for recognizing the presence of other persons and their availability for interaction, and creates incentives to initiate conversations. A system that supports both video and audio communication is especially suitable for enabling informal communication (Kraut et al., 1990).

Studies (Johansson & Törlind, 2004, Törlind & Larsson, 2002) have shown that many of the contemporary collaboration tools for distributed teamwork, e.g. video conferencing and shared applications, can support formal meetings to a certain extent. But to adequately support informal meetings, distributed social activities and informal communication processes that often arise spontaneously in between the formal meetings are important issues yet to be resolved. The vital informal component in teamwork communication has so far been difficult to support in collaboration applications (Johansson & Törlind, 2004). Larsson (2002) points out that the formal approach of holding meetings through telephone or videoconferences do not entirely fit the way in which geographically dispersed teams need to interact in order to "get the work done". These tools are often useful and critical to the project, but are missing the elements of day-to-day interaction between members. Finding a good time to interact, and being able to establish easy and rapid connections with co-workers need to be better supported in the technologies for distributed collaborative work. Otherwise there is a risk that the social collaboration process is reduced to a formal process where team members are "explaining to each other" instead of "thinking together" (Larsson, 2002). Extra formality and inflexibility should not be introduced into distributed collaborative teamwork without special consideration (Larsson, 2002).

3 COLLABORATIVE MOBILE COMPUTING

Often when mobile computing is adopted to improve collaborative work, the existing concept of the desktop-based computer is transformed to mobile platform. It has resulted in that the potential of mobile computing have not properly exploited (Rebolj et al., 2004). York & Pendharkar (2004) make a distinction between mobile and portable computing and their respective user groups. Users of portable computing are typically professional white-collar workers using wireless communication from laptop computers to remotely access office documents, e-mail, and corporate knowledge applications, while users of mobile computing are a more diversified group ranging from health care providers to blue-collar service workers (York & Pendharkar, 2004). Kristoffersen & Ljungberg (1999) explain the fundamental differences between the mobile work context and the office setting. In mobile work the tasks external to operating the computing device are most important, as opposed to tasks often taking place "in the computer" in the office setting. The hands of the mobile worker is often used to manipulate physical objects, as opposed to users in the traditional office setting, where hands are safely and ergonomically placed on the keyboard. In a mobile work environment users may be involved in tasks "outside the computer" that demand a high level of visual attention to avoid danger as well as monitor progress, as opposed to the traditional office setting where a large degree of visual attention is usually directed at the computer. Mobile workers may also be highly mobile during the actual task, as opposed to in the office, where doing and typing are often separated (Kristoffersen and Ljungberg, 1999).

Mobile computing often takes place in a heterogeneous environment with a varied context of time and space. Context changes can vary in frequency, speed, and predictability. In some mobile applications the time in which a task takes place can be just as critical as the location, and could have implications for the fit of a computing device (Baber et al., 1999). Additionally, the change of user needs as users change work contexts while using an application needs to be regarded (York & Pendharkar, 2004). Central to mobile computing is that technologies should disappear into the background so that users can unconsciously apply them to the task at hand. Mobile computing is often related to the concept of "ubiquitous computing", meaning that machines should fit the human environment instead of forcing humans to enter theirs (Weiser, 1991). To accomplish this, the practices and every day work of people must be understood and supported by an appropriate technology solution. Furthermore, heterogeneous solutions should be available to offer a variety of interactive tools for different situations, and when these solutions are networked they should provide a holistic user experience (York & Pendharkar, 2004).

Johansson & Törlind (2004) underline that mobility support is essential for both formal ICT applications and informal communication tools in distributed work environments. Mobility is vital to create awareness - awareness of people (a sense of who is around) and awareness of process (what they are doing). Maintaining awareness across distance is crucial for successful collaboration (Johansson & Törlind, 2004). In the daily activities on a construction site interactive personal communication is the basis on which unanticipated events and critical problems are solved. Magdič et al. (2004) suggest that the continuous process of problem solving is most effective if it relies on a personal decentralized level supported by mobile computing technology. Čuš Babič et al. (2003) describe that there is a twofold information flow in the construction process; an official flow of documents (progress reports, cash-flow reports, survey reports, daily plans, etc.) and an informal communication between different levels of organization concerning work progress, quantities, financial data and on-site problems. If the informal communication is not effective in this complex process it may cause delays and disruptions with lower productivity and financial losses as a result. Mobile computing can provide powerful tools to support these activities and make the information more available and the communication faster and more reliable (Čuš Babič et al., 2003).

This paper argues that mobile computing can enable better support for informal communication which is essential in handling unanticipated events and solving critical problem situations that constantly occur at construction sites. Improved informal communication has positive effects on many intangible factors like improved collaboration, mutual understanding and enhanced team relations that result in better project results and increased productivity. Mobile computing can enable information control and that data collected in the field will be more structured and consistent. All submitted and received information and data is saved, which enables their immediate use and subsequent control (Magdič et al., 2004). Mobile computing can deliver good access to timely and accurate information, and quick and efficient communication with on- and off-site personnel. This can reduce or maintain project durations, make better use of resources, increase labor and equipment productivity and decrease cost (Bowden & Thorpe, 2002). Olofsson & Emborg (2004) imply that mobile computing systems can cut lead-times, create better workflows, use resources more efficiently and increase the value for the customers. Much of the positive effects can be derived from the fact that mobile computing can save hours in travel. That time can be used in doing productive work. Mobile computing can enable delivering information "just-in-time", which allows contractors to reduce work-in-progress inventory, and thereby working capital. Reduction of cycle times and flow variation are additional benefits derived since resources materials, equipment, and personnel will spend less time in queues waiting to progress forward (De la Garza & Howitt, 1998). Other time saving effects that mobile computing can bring are improved problem solving speed which reduces the risk of crisis and cooperation between personnel becomes less distance sensitive (Magdič et al., 2004). Boussabaine et al. (1999) indicate that a wireless ICT system at a construction site could enable time savings in the order of 40-120 days per year.

It is not difficult to understand the great potential of mobile wireless data communication in a construction environment. Just look at the case of walkie-talkie and its impact on wireless voice communication at construction sites. The walkie-talkie has played an invaluable role in wirelessly supporting the spontaneous informal verbal communication for handling unanticipated events and solving critical problems that constantly arise at construction sites. But what is missing in a walkie-talkie is the spontaneous on-demand flow of information-rich data, documents and drawings which is a vital component of construction projects today. If this information combined with improved communication tools could be obtained wirelessly at the specific location where a construction task is being carried out, mobile computing has the potential of improving productivity more than has been achieved so far by the walkie-talkie (De la Garza & Howitt, 1998). To accomplish this, mobile computing platforms must be able to deliver powerful applications with an interface as simple and intuitive as the "push to talk" feature of the walkie-talkie. To create a future all-inclusive handheld mobile wireless ICT platform (voice and data) for project collaboration is a major challenge and incentive for improving productivity in the construction process.

4 SOCIO-TECHNICAL ASPECTS OF IMPLEMENTATION

The issues of implementing a mobile computing system are complex and numerous. Network architectures, wireless infrastructure equipment, handheld computer devices, information systems, communication services, distributed collaboration tools and other applications have to be chosen and planned carefully in detail to meet the requirements and behaviors of the mobile workforce. This section will briefly highlight some important socio-technical issues of an implementation strategy for collaborative mobile computing at construction sites. Different wireless infrastructure and networking alternatives as well as capital and operational costs will not be considered here.

4.1 *The socio-technical gap*

To strategically implement and integrate an ICT system into an organization there has to be an alignment between the work processes and the technology (Aouad et al., 1999). ICT systems and work processes have to be co-developed to be able to improve organization and increase productivity. When introducing collaborative ICT systems into existing work environments and business processes it is important to recognize the fundamental socio-technical gap between what is required socially and what can be done technically (Ackerman, 2000). This social-technical gap is difficult to overcome, but it can be better understood and approached. It is critical to understand the targeted environment, the needs and behaviors of the intended users and how people really work in groups and organizations to be able to prevent the introduction of unusable systems that are mechanizing and distorting collaboration and other social activities. In stead, a problem-driven demand-pull approach should be applied to identify and utilize the potential application areas for ICT tools in construction (Björk, 1999).

4.2 *Organizational perspectives*

Based on Samuelson (2003) the implementation and use of ICT in construction can be described consisting of three levels of organizational perspective; individual/personal, project/group and corporate/industry level. Many of the problems associated with ICT in the construction industry are related to its adoption, which has been relatively uncoordinated, and its strategic application appears to have been determined by its availability rather than its suitability (Aouad et al., 1999). When introducing new ICT solutions into organizations it is important to review all three of the organizational levels and realize that different viewpoints of adoption strategy are needed on different levels.

First of all, the individual user perspective is especially important to recognize to achieve user acceptance and profitability of the mobile computing system (York & Pendharkar, 2004). Otherwise the integration of information systems into the work environment could hinder the workflow or frustrate users, who will struggle with operating the user device instead of doing the intended work (Larsson, 2002). The three main factors limiting the broad appeal of mobile and wireless computing are deficient ergonomics and usability of mobile wireless systems and user devices, the lack of practical, personal, and timely interaction tools, and that the workflows for mobile workers are still largely paper-based and lack automation and integration (York & Pendharkar, 2004). The lack of openness of the information and communication culture of an organization can also limit the adoption of a mobile computing platform. In contrast, an open culture can encourage the adoption and utilization of new ICT tools to improve availability and visibility of project deliverables, and strengthen involvement and feeling of responsibility by all project participants (Aouad et al., 1999).

4.3 *Level of mobility*

The mobility issue itself gives rise to several aspects that need to be handled in the implementation strategy. Pierre (2001) accentuates that a true mobile computing infrastructure should be able to support different wireless and wireline communications devices optimized for their specific environment. In this way, a person would be able to communicate and receive information anywhere, any time. Service portability represents a dynamic relationship between a terminal and a user to provide applications and services to a user's present terminal or location. The applications and services that can be provided to a user depend on the capability of both the terminal and the network in use. Service portability can be provided through so-called Intelligent Network capabilities (Pierre, 2001).

The needed level of mobility is decided by the specific requirements of the construction site. For example, is the system required to support continuous operation of applications while users move between network boundaries? What level of mobile awareness should be supported by the system? Does the system need to support multipoint distributed conference applications? How heterogeneous are the networks and the devices? The answers to these and other relating mobility issues assist in narrowing down the possible choices of suitable technology solutions for a collaborative mobile computing platform.

4.4 *Applications and services*

An implementation strategy of a mobile computing network must also include an appropriate mix of applications and services. On a general level, there are two types of mobile applications and services; horizontal applications which are domain independent (e.g. web-based public information services), and vertical applications which are written for a specific application domain that respond to the specific needs of a mobile work force (Pierre, 2001). It is important to identify what information and communication needs are not sufficiently supported and how this could be resolved.

Aziz et al. (2004) describe how semantic web, web services and agent technologies in a mobile environment can improve construction collaboration. Because of the temporary, multi-organization structure of many construction projects where companies work together for a short period of time, the approach of loosely coupled web based platform is well suited for the construction industry (Aziz et al., 2004). One of the keys to realize fully ubiquitous mobile collaboration tools is to develop systems and applications that are adaptable and scalable to heterogeneous conditions of bandwidth availability and end user equipment capabilities (Johansson & Törlind, 2004).

4.5 *Integration of existing ICT systems*

Integration of existing information systems into a mobile computing platform is of critical importance. It is essential that mobile computing does not add another incompatible stand-alone ICT structure that fragments the construction process even more (Bowden & Thorpe, 2002). A mobile computing platform must be integrated with existing information systems and project collaboration tools in order to achieve a seamless flow of information throughout the whole construction process and to make use of the benefits of the information generated in earlier phases of the project. However, mobile computing differs a lot from traditional desktop computing, and an application that is designed for a fixed desktop-oriented platform may not deliver the same effective solution in a mobile environment (Rebolj et al., 2004). But still, merging existing information structures to create better integration and organization between design, planning and construction phases are imperative to increase productivity and improve the quality of the construction process (Stewart et al., 2002). Even though there is still a long way to go, the construction industry is trying to move towards a standardized exchange of data and fully integrated, digitalized product and process model oriented construction projects. If mobile wireless ICT technology can enable informal and intuitive utilization of existing formal information structures in critical problem solving situations, then mobile computing can be the link to bring an inclusive digital platform to the construction sites to enable increased integration and collaboration between the design phase and the building process (Rebolj et al, 2004).

4.6 *User devices and interface*

The mobile computing solution introduced at a construction site must meet the special demands on durability, user interface and be able to handle operation in harsh environments, otherwise the promised rationalization will be lost (Olofsson & Emborg, 2004). Overcoming the limitations of the user devices is a critical issue in this context. Although handheld computers are improving rapidly, they still suffer from small screen size, slow text input facilities, low bandwidth, small storage capacity, limited battery life, and slow CPU speed (Pilgrim et al., 2002). Of particular importance is the screen size and resolution. Small screens often have a negative effect on browsing related tasks because there is too much data and too little display area to present the information (Pilgrim et al., 2002). Data models in engineering applications tend to be complex and to designing the corresponding mobile device user interface is challenging. Also, compared to the design of desktop-oriented software there are relatively few guidelines available to aid the interface design of mobile computing devices (Pilgrim et al., 2002).

In recent years, wearable computers have gained interest by various mobile work organizations. Wearable computers are carried on the body, generally on the head, arm, back or around the waist. But there are problems associated with the user interfaces of wearable computers. Baber et al. (1999) imply that head-mounted displays even with minimal weight can have negative impacts on user posture and performance. Head-mounted displays cause an increased range of head movements and reduce situational awareness by competing with environmental visual demands (Baber et al., 1999). Audio input and output that is often featured in wearable computers can be difficult to implement in mobile computing work environments (York & Pendharkar, 2004). Audio input and output is suitable in a low-noise environment, which is not the case at construction sites.

5 TOWARDS A RESEARCH FRAMEWORK

So, what is the next step for mobile computing in construction? As has been presented in this paper there are a lot of unresolved issues. This final section summarizes the described topics and attempts to outline a schematic research framework to approach these issues. The socio-technical perspective is central in this framework. Before incorporating new technology into the construction process, one must understand the complexity of use and implementation, survey the positive and negative effects of the technology on the existing work procedures, and know how to manage the technological and organizational changes in the processes. To accomplish effective mobile computing at construction sites, technology solutions need to be developed and implemented with a bottom-up approach recognizing end user and group needs and the separate issues of adoption strategy on different organizational levels. By mapping established research fields to the three organizational levels mentioned previously, a general socio-technical bottom-up research framework for collaborative mobile computing in construction can be outlined. Human-Computer Interaction (HCI) issues need further research at the individual/personal level. The research perspectives of Computer Supported Cooperative Work (CSCW) and Groupware have to be addressed at the project/group level. Methods concerning management of technology and innovation processes have to be developed at the corporate/industry level.

The remaining part of this section will explain the basic concepts and approach of this research framework.

5.1 *Human-computer interaction (HCI)*

The field of HCI is concerned with the design, evaluation and implementation of interactive computing systems for human use. Use and context of computers, human characteristics, computer systems and interface architecture, and the development process are four main areas of research in HCI (York & Pendharkar, 2004). An important issue in this context is the user acceptability of a system. A system that satisfies the needs and requirements of the users is an acceptable system and has a high level of "usefulness"; the system is capable of achieving the desired goal (Berg von Linde, 2001). Usefulness can be divided into utility, the level of functionality of the system, and usability, how well a user can utilize the functionality of a system (Berg von Linde, 2001). The usefulness perspective is crucial to be able to design suitable mobile computing systems with appropriate user interfaces that meet the user needs in a demanding and heterogeneous construction environment. One of the true challenges in this context is the limitations on the screen size and resolution of handheld computers. In the case of the construction site, graphical data such as maps and drawings are an essential part of the information flow in the work process. The question is how should this information be visualized on a handheld computer to be useful? More innovative forms of information visualization interfaces combined with development of user devices are needed for the mobile computing environment. Another HCI issue concerning mobile computing at construction sites is to design ubiquitous and "invisible" user applications and interfaces that enable the user to focus on their work at hand. Context aware forms of computing that makes interaction between a user and a computing machine less distracting are interesting concepts in this perspective (York & Pendharkar, 2004).

5.2 *Computer Supported Cooperative Work (CSCW) and Groupware*

Like HCI, the CSCW research field is socially oriented rather than technology driven. CSCW studies how people work together, and how computer and ICT related technologies affect group behavior. By looking at the way people interact and collaborate, technology can be developed that properly supports these collaborative activities (Larsson, 2002). The term CSCW is often associated with the term Groupware. Groupware are the computer-based systems that support group work to achieve a common task (Greenberg, 1991). Groupware systems assist both groups of people working together and also single individuals performing isolated tasks. CSCW relates to groupware in the sense that it defines the scientific discipline that motivates and validates groupware systems design (Greenberg, 1991). Groupware communication technologies can be divided into time and location of communication, distinguishing between synchronous (real-time) and asynchronous (different times) work, and between co-located (same place) and distributed (different places) settings (Larsson, 2002).

The challenge for the CSCW and groupware perspective is to understand the socio-technical gap of what is required socially within a work group and what can be done technically. This is a critical issue to be successful in designing and implementing mobile computing at the group/project level. It is important to understand how people really work in groups and organizations so that the introduction of new ICT systems do not deteriorate and distort the collaboration process and social interaction. Before implementing collaborative mobile computing at construction sites, the culture, social structure, communities of practice and the tacit knowledgebase of the group/project level have to be understood. When these mechanisms are identified and the relationships between them are recognized, then a collaborative mobile computing platform can be designed to truly support the existing knowledge formation, develop and enhance organizational capabilities and improve collaboration and project communication in the construction process.

5.3 *Management of technology and process innovation*

The term "enabling technology" can be used to describe a technical solution that is introduced into an organization's production operations in order to enable productivity increase and to improve work procedures and organization. These improvements of an organization's production are often referred to as "process innovations". Process innovation can often be described as a discontinuous productivity advance because the enabling technology is making the production more efficient (Utterback, 1994). A major discontinuous change is usually followed by a number of small, incremental improvements. A collaborative mobile computing platform can be regarded as an enabling technology for the construction process. It is important point out that mobile computing is not that kind of enabling technology that creates process innovations that will change the physical construction process, i.e. the way buildings are built. Nevertheless, as this paper has described the contribution of mobile computing can enable radical innovations in the information and communication processes that surround the entire construction process, which can lead to significant productivity increase.

Process innovation is usually divided into technological and organizational process innovations. Technological and organizational processes often go hand in hand with many interdependencies between them. Introducing an inclusive mobile wireless ICT platform at a construction site is a technological process innovation, while the improvements in work procedures, organization, communication, information flow and project collaboration created by mobile computing are organizational process innovations. A socio-technical approach where technological innovation and implementation aspects interact with work practices and human factors is essential for successful management of technology and process innovation at the corporate/industry level. Therefore, the management of collaborative mobile computing in construction needs to be approached from two directions, where both technological and organizational innovation aspects have to be handled and developed in conjunction. When introducing new technology into the production operations of an organization, the first problems encountered will probably be of technological character. As the technological problems are solved, problems will be of a more organizational character related to the use and integration of the technology. Therefore, the focus of management will be different as technologies evolve (Drejer, 2002).

It is important to stress the process perspective and the enabling role of mobile computing. The technology management of mobile computing needs to be addressed as an enabler that should be integrated with the production process, instead of a process independent driver. This becomes evident when looking at the failing of ICT in many parts of the construction industry. While ICT solutions have been introduced through various professions, there has been a lack of focus on the integration and use of ICT to improve construction project collaboration process on a holistic level (Aouad et al., 1999). In this perspective the issues of Robert Solow's computer-productivity paradox is also important to address. Solow's famous statement "You can see the computer age everywhere but in the productivity statistics" (Solow in Triplett, 1999) raises a lot of questions concerning the implementation of collaborative mobile computing in the construction process; first of all, is there a computer-productivity paradox at all? What impact will the adoption of mobile computing have on productivity in the construction process? How should the productivity effects of mobile computing be measured? Can the effects of mobile computing on productivity be measured at all? In general, a continuous critical discussion of ICT solutions and what improvements they are supposed to bring to the construction process is needed to confront and manage the computer-productivity paradox and to avoid failures when introducing ICT in the construction industry.

The research framework for collaborative mobile computing in construction sketched above needs a lot of development. The purpose of this paper is only to outline the fundamental cornerstones in this framework. Nevertheless, the point is that a socio-technical bottom-up approach that recognizes end user and group needs is critical to able to effectively design, implement, use and manage collaborative mobile computing in a mobile distributed heterogeneous construction environment.

6 CONCLUSIONS

Changes of plan, unanticipated events and temporary critical problems are inevitable at construction sites. The need for appropriate information-rich communication tools in this environment is not well addressed today. Informal communication plays an important role in handling unanticipated events and solving critical problems. Informal communication is also vital for improving project collaboration, social group relations and teambuilding processes. The problem today is that informal communication is poorly supported by information and communication technology. High level of mobility and awareness in ICT tools are important to be able to support efficient ICT-based group communication in distributed work environments. The rapid developments of wireless mobile computing technologies over the past decade have brought new opportunities to the information and communication issues at construction sites. These technologies have now the potential to provide a complete wireless mobile ICT platform (voice and data) that can enable improved support for informal communication and on-demand data at construction sites, which can result in improved project collaboration leading to increased efficiency and productivity in the construction process. Towards accomplishing this, valuable experience can be obtained from the example of the walkie-talkie and why this technology has become a powerful tool for verbal informal communication at construction sites. Likewise, the breakthrough and user acceptance of a mobile computing platform in the construction process depends much on whether such a system can be designed to deliver powerful applications with an interface as simple and intuitive as the "push to talk" feature that the walkie-talkie provides.

An implementation strategy for collaborative mobile computing at construction sites must consider numerous issues regarding system capabilities, mobility, applications, services, integration of existing ICT systems, user interface and user devices to meet the requirements and behaviors of site workers. A socio-technical bottom-up approach is needed to able to improve the design, implementation, usage and management of collaborative mobile computing in a mobile distributed heterogeneous construction environment. Different viewpoints of technology implementation and adoption strategy are needed on different organizational levels. Human-Computer Interaction (HCI) issues need a lot of consideration and further research at the individual/personal level. Usefulness concerning utility and usability of system applications and user interfaces are important aspects to meet the specific needs and behaviors of construction site workers and to achieve high user acceptance of the mobile computing system. Computer Supported Cooperative Work (CSCW) and Groupware have to be addressed at the project/group level. The challenge of this perspective is to understand the socio-technical gap of what is required socially within a work group and what can be done technically with mobile computing. Understanding how people really work together, the culture, social and organizational structures, communities of practice and the tacit knowledgebase of a construction site is essential to be able to design a collaborative mobile computing platform that truly supports the existing knowledge formation, develops and enhances organizational capabilities and improves collaboration, social interaction and project communication in the construction process. Methods concerning management of technology and innovation processes have to be developed at the corporate/industry level. The management of collaborative mobile computing in construction needs to be approached from two directions, where both technological and organizational innovation processes have to be handled and developed as one integrated unit. It is critical to approach these management issues with a broad construction process perspective and accentuate the enabling technology role of mobile computing for improving collaboration and project communication throughout the whole construction process. This combined with a critical discussion of what effects mobile computing will have on work flows and productivity and how this should be measured, are key points to avoid impulsive and expensive ICT failures in the construction industry in the future.

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Professor Örjan Wikforss, Department of Industrial Economics and Management (INDEK), Royal Institute of Technology (KTH), Stockholm, Sweden

Professor Staffan Laestadius, Department of Industrial Economics and Management (INDEK), Royal Institute of Technology (KTH), Stockholm, Sweden

Associate Professor Per Andersson, Center for Information and Communication Research (CIC), Stockholm School of Economics, Stockholm, Sweden

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