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ANALYSIS AND DESIGN OF MOBILE COLLABORATIVE APPLICATIONS USING CONTEXTUAL ELEMENTS

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Abstract. Collaborative mobile applications support users on the move in order to perform a collaborative task. One of the challenges when designing such applications is to consider the context where they will execute. Contextualized applications are easy to adopt by the users; unfortunately the design of contextualized tools is not evident. This paper presents a framework of contextual elements to be considered during the conception, analysis and design phases of a mobile collaborative application. This framework supports developers to identify non-functional requirements and part of the architectural design in order to get contextualized applications. The use of this framework is complementary to any structured software process. A framework use example is also presented as an illustration of its applicability.

Keywords: Groupware design, context, mobile collaboration, software development

1 INTRODUCTION

Many people need to be on the move to accomplish their jobs. The last technological advances have allowed people to work on a plane, bus, subway or just when walking. However, it has also brought new design challenges for software applications. In the case of mobile collaborative applications, part of these challenges are to consider the conceptual migration from complex and heavy software running in fixed computers [28] to lightweight software encompassing wireless communication and mobile computing devices such as laptops, Tablet PCs, PDAs and cellular telephones [3, 24, 32]. Under this scenario, new interaction paradigms identifying the physical environment as a protagonist [11] should be understood and considered. Hardware limitations of mobile computing devices [18, 23] are also part of the challenges to face.

Several authors have attempted to identify the possible causes of unexpected successes and failures in groupware systems. For instance, Grudin identifies the importance of designing groupware taking into account not only technological issues but also the complex social dynamics within which group activity occurs, e.g., social, motivational, political and economic factors [20]. He recommends a sophisticated understanding of the prospective users' workplace. Ljungberg and Holm analyze conversational systems and found them drastically decontextualized [27], i.e., they do not consider the wide social context where interaction actually occurs, assuming a stable and immutable role structure. Bardram reaches the same conclusion while analyzing a groupware system to support health-care workers [5].

As stressed by these authors, the problem is that typical design of groupware systems does not consider the context where these systems will be used. Most groupware developers usually focus almost exclusively on the analysis and specification of functional requirements which are the basis of the design and system implementation. However, the non-functional requirements are those which assure the applicability and usability of a software solution in a work environment. Although some non-functional requirements are usually considered (e.g. the users' attitude towards collaboration), there is no formal process helping developers identify and understand the requirements within a broader and contextualized perspective.

This paper presents a contextual element based framework intended to support mobile collaborative systems developers to understand the application context and to use such context during the development process. As a result of using the framework, developers can identify a set of relevant non-functional requirements and design restrictions in order to get a contextualized application. The framework classifies context elements into eight categories, which are progressively considered through conception, analysis and design phases. This process can be embedded in a typical software life cycle. Next section presents our understanding of the context concept. Section 3 presents the context-based framework for designing collaborative mobile applications. Section 4 analyzes the application of the framework to an example case, and Section 5 presents some conclusions.

2 UNDERSTANDING CONTEXT

There is no consensual definition of context or what it comprises. Context has been described, e.g., as a set of preferences/beliefs, a set of objects in a graphical interface that belongs to a certain region or window where the user's action takes place, a set of attributes, a set of characteristics of the situation at hand and the knowledge use goals, a set of knowledge pieces related to a particular activity or situation [9]. In a broader sense, context can be understood as "the interrelated conditions in which an event, action or situation takes place"[1]. Other definitions follow that direction: context can be seen as "a complex description of shared knowledge within which an action or event occurs" [36], or as "whatever does not intervene explicitly in a problem solving but constrains it" [8].

Research works in the "context" topic seem to agree in two aspects: First, context is regarded as whatever surrounds something, e.g., situation, an activity, an idea, but is not the thing itself. For instance, in the area of context-aware computing, user context is described as the conditions associated to the users' current location, such as social aspects or physical properties [13]. In groupware, contextual information is provided to group members about several aspects related to their joint work while they are collaborating. Thus, they can understand how their actions fit into the group goals, which are the conditions closely related to their current activity and how the actions of their team mates change such conditions [7, 36, 37]. Second, context comprises a set of elements that keep a coherence relationship bringing a particular meaning to the thing, e.g., situation, an activity, an idea. Thus, we can analyze a software product in the context of its technical capabilities finding its successes and failures; if somebody criticizes the product by arguing that it may change the political order in an organization, we may say such argument is out of context or it corresponds to a broader context.

Several attempts have been made to identify various kinds of context. Brezillon et al. distinguish three main parts of context which can be understood as three major scopes: external knowledge – knowledge not relevant to the situation at hand but shared by group members –, contextual knowledge – knowledge relevant to the situation at hand – and proceduralized context – knowledge concerned with whatever is actually happening [8, 10]. Brezillon et al. also distinguish group, project and individual contexts [8]. On the other hand, Chen and Kotz identify four types of context: *physical* – lightning, noise level, traffic conditions, temperature, *computing* – network connectivity, communication cost, bandwidth and nearby resources, *time* – time or day, season and *user context* – users' profile, location, people nearby and social situation [13].

McCarthy claims that the contextual dimensions are infinite [31]. Although insightful, these classifications of context are not conceived for supporting groupware design, but for creating applications that react in some way to context changes. As our interest focuses on collaborative mobile applications design, we are proposing

[1] Excerpt from Merriam-Webster on-line at `http://www.m-w.com`.

a context framework reorganizing such approaches and including insights found in groupware research.

Several experiences in the use of groupware applications have shown the lack of flexibility of these tools to support collaboration in various scenarios [5, 20, 27]. Typically, the physical context describing the physical characteristics of the collaboration scenario and the social context including users' particularities and their interactions are not considered during groupware application design. The influence of the context elements during such design is so important that it is really difficult to develop a successful groupware tool without considering these contextual elements. Our aim is to support groupware design by providing a framework comprising some context elements that must be considered during analysis and design. Some of them may possibly become a relevant source of information for designing useful groupware features for the final users (e.g. awareness information [22, 34]) and other ones may become non-functional requirements. Some decisions must be made while designing the system, but they require a comprehensive analysis of the situation where the system will run. Hence, we must focus on the various kinds of context related to the physical environment where the groupware system will be used. From this perspective, we understand context as "everything that is significantly related to the future groupware application" and must be considered for proper groupware design. Next section presents the proposed framework intended to help designers consider relevant context elements when developing mobile collaborative applications.

3 A FRAMEWORK OF CONTEXTUAL ELEMENTS

A conceptual framework to support analysis and design of collaborative mobile applications is proposed based on the authors experience and the relevant literature. It can be used to identify the relevant non-functional requirements and design restrictions that help developers get contextualized applications. This process is continuously evolving. Thus, the product of each phase is an increasingly comprehensive and accurate list of non-functional requirements and design restrictions. The functional requirements that could be identified during this process are specified in a parallel way. This latter part is not included in the framework process. The framework identifies and categorizes a subset of key contextual elements that may be relevant for this purpose. It must be emphasized we are not proposing a new software development process, since we assume a typical process is being used, i.e., a software development process including at least the conception, analysis and design phases. Figure 1 relates our framework to a process considering the mentioned phases. Eight different contexts must be analyzed during these phases: Social, Collaborative Task and Activity contexts during the Conception phase, Organizational, Group and Physical contexts during the Analysis phase, and Technological and HCI contexts during the Design phase. Arrows show the analysis ordering of these contexts during the development process. Therefore, this framework can be considered as a guidance tool to strengthen some development activities of mobile collaborative applications.

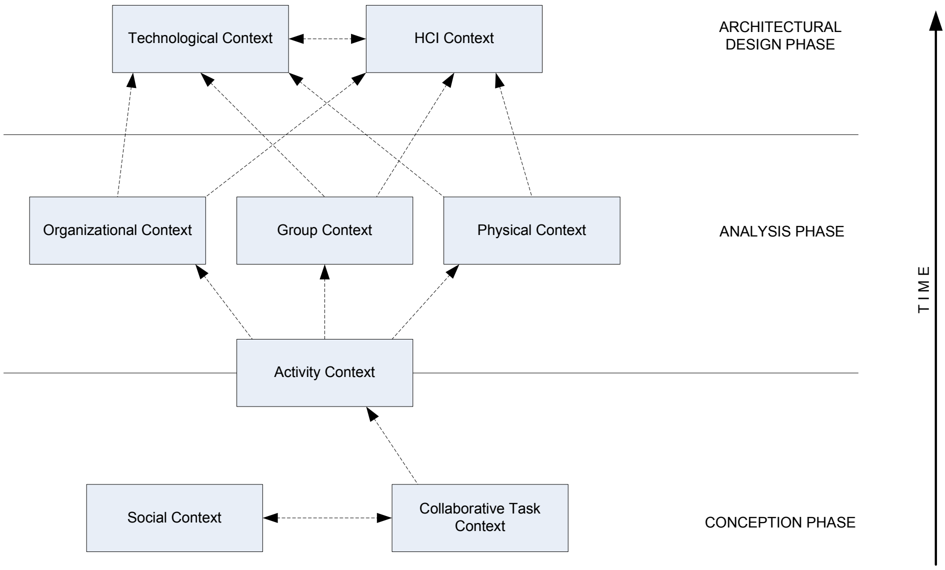


Fig. 1. Design context for collaborative mobile applications

The context elements are organized into eight types of context realms arranged in three layers according to the software development phases: conception, analysis and architectural design. The conception phase comprises the social and collaborative task contexts (the lowest layer in Figure 1). These contexts assist application developers to understand the system requirements from a broad perspective. The social context characterizes the users' capability to collaborate using technology. The collaborative task context establishes the main features of the task including the common goal and the support needed for mobile users. An extensive analysis requires this context be decomposed into several activities corresponding to use cases. Such activities may involve different interaction scenarios, each of them having its own context. Hence, the collaborative task cannot be considered as related to a homogeneous context. Context elements in the conception layer influence context elements of the upper layers.

A further analysis is carried out for the activities in the second phase. Organizational, intra-group and physical contexts must be defined for each activity. The understanding of all these context elements will influence and constrain the design options for technology support and interaction style in the third phase (Architectural Design in Figure 1). The context elements involved in each phase are presented below.

3.1 Phase I: Conception

The conception phase deals with understanding the problem domain. Therefore, the relevant contexts are those related to the general scope of analysis. The phase main goal is to determine the feasibility of a solution and its restrictions. This feasibility will depend on the capability to balance the social context and collaborative task context. In other words, it should be decided whether the collaborative task can be done by the users or not. The first step is to identify the application users' domain.

3.1.1 Social Context

It is hard if not impossible to ascertain exactly what social context comprises, because all human actions are ultimately rooted in the social context. For the sake of practicality, we consider some aspects that had been proved to be important in groupware design and we provide developers with information regarding the prospective user:

Readiness to use IT. The goal is to determine the group members preparation for using Information Technology tools. Users' experience, readiness to use technology and learning will influence the kind of interaction dialogues, interfaces, protocol design options and even the project feasibility.

Previous formal context (e.g., rules and regulations). These issues will help characterize users' information needs, as well as the actions the group should perform for conforming such regulations [14].

Previous informal context (e.g., social conventions and protocols). Unlike formal contexts, social conventions naturally emerge during everyday users' interactions. They cannot be imposed and they constitute a frame for understanding each other behavior and purposes [14, 30]. In this category we must consider the consequences of violating the informal conventions [29]. The interaction situations at a social scale must also be taken into account (e.g. collaboration, competitiveness, and independency).

Work practice tools. Every work practice community usually develops its own tools [4]. These tools are not necessarily supported by technology. The analyst can understand the current underlying workflow by studying these tools, since they mediate social interactions. For instance, patient records in a hospital are useful to doctors and nurses wishing to coordinate their actions [35].

Table 1 suggests some questions which can be asked for a particular interaction scenario for determining the most relevant Social context. Answering these questions will help assess the feasibility of a solution. In case of being feasible, these answers will also restrict the number of solution options.

The analysis being done while trying to answer the questions stated in Table 1 should complement customary studies typically recommended for the Conception phase, such as economic or development time analysis. All the works make up

Pre-conditions: 1. We know the group members' identities.	
Readiness to use ITs	Are group members already using computing devices? What type of computing devices are the users familiar with? What type of devices may they be willing to learn how to use?
Previous formal context	What rules and regulations restrict the information access, coordination and responsibilities?
Previous informal context	Are people willing to collaborate or have a collaborative attitude towards their teammates? Is there a social protocol specifying the way people interact at work?
Work practice tools	What work practice tools are used by the community? How does the community use them?
Post-conditions: 1. We know whether the group members are able or not to use a technological solution. 2. We know the usability restrictions the solution will have to satisfy in order to be suitable for the users. 3. We know the type of training required by the users, if any. 4. We know the (formal and informal) social conventions that influence the users' behavior. 5. We have an insight of the way people work.	

Table 1. Social context elements

a comprehensive feasibility study. The Conception phase continues with a second step: characterize the collaborative task to be carried out by the group.

3.1.2 Collaborative Task Context

At this stage the analysis will assist developers to determine if a mobile groupware solution is required. In such case, the proposed framework will help developers continue with the analysis and design process towards a mobile solution. The main issues are analyzed below.

Activities: An important issue to be decided is whether or not the task can be split into several activities or use cases. Relevant features of each activity such as urgency and importance should also be identified. Once this issue is settled, the activities and their relationships should be identified [17, 37].

Group members interaction. We must identify general interaction scenarios among group members in order to determine which of them require mobile support. Such interaction must consider users' communication needs for data and/or voice transfer.

Pre-conditions:

1. We know the common goal of the collaborative task.

Activities	What activities compose the collaborative task? What workflow could link these activities?
Group members interaction	Do users need/want to be on the move while working? Do users need to be reachable any time/place? Do users need to transfer data while moving?

Post-conditions:

1. We know the number of activities and an insight of the task complexity.
2. We know which activities require mobile computing support.
3. We have a preliminary analysis of the main application requirements (e.g., urgency, importance, negotiation, mobility, roles, physical locations).

Table 2. Collaborative task context

Answers to questions in Table 2 are very relevant for the analyst to decide how to continue with the design of the application. As shown in Figure 1, the next step is to study each activity, something we consider to be done between the conception and analysis phases.

3.1.3 Activity Context

Typically, a collaborative task can be split into a set of activities that must be carried out coordinately to accomplish the task [18]. Only activities requiring mobile computing support are being considered in the framework. Each activity has its own context, and the issues relevant to consider during the application analysis and design are the following ones:

Work interaction: Group members perform activities in a synchronous (coupled or joint) or asynchronous (uncoupled, independent or parallel) mode. When collaborators require moving around in order to accomplish a function or a specific activity, it is necessary to provide mobile support; otherwise the activities are called fixed or located. Hence, activities may be characterized as mobile/coupled, mobile/uncoupled, located/coupled and located/uncoupled. An activity may also be mixed, i.e., it may be in one of these situations and then be in another one as time passes. This characterization provides an understanding of technological restrictions and interaction requirements, contributing to the feasibility analysis during the conception phase. Mobility types are traveling, wandering or visiting [26]. Traveling is defined as the process of going from one place to another in a vehicle. Wandering, in turn, refers to a form of extensive local mobility where an individual may spend considerable time walking around. Finally, visiting refers to stopping at some location and spending time there, before moving on to another location.

Communication requirements. Communication can be direct or mediated; public, private or a mixture; broadcast or multicast. In addition, the elements to be communicated can be data, voice or events. This issue is settled during the analysis phase. Communication strategies constrain the coordination strategies that can be applied.

Coordination requirements: Coordination elements and policies need to be identified. Some of these elements are: support for session management; floor control administration; user roles support; shared information handling. A strict coordination strategy may be needed for activities with a high degree of parallelism. Besides, we must identify the activity stages requiring off-line work (data synchronization may be needed).

Criticality: It is important to determine the urgency of achieving the activity goals and the activity importance for the user. These criteria may influence the choice of communication and coordination strategies.

Duration: Except for the case of mobile phones, activity duration in mobile collaboration based on PDAs, notebooks or Tablet PCs can be critical as it could be restricted by battery life [18, 25]. Although it is possible to carry extra batteries, we may optimize the use of power supply by identifying activity duration and designing according to it [13, 21].

Once the Task context has been defined in a global way, it is necessary to disassemble the collaborative task into several activities or use cases. This can be done by taking into consideration, at least, the suggested contextual elements listed in Table 3.

Notice that analysis of the elements in Table 3 completes the well-known three main components of collaborative work: collaboration, coordination and communication [15]. It also includes thinking about our specific mobile requirements.

3.2 Phase II: Analysis

The goal of this phase is to continue understanding the problem in order to identify design restrictions and non-functional requirements regarding organizational, group and physical contexts. The categories below describe the involved issues.

3.2.1 Organizational Context

Various authors distinguish group and individual contexts [14, 37]. We do not explicitly consider individual context since we are concerned with the understanding of group context for applications design. Furthermore, we consider the difference between Organizational and Group contexts. The former one concerns the organization to which the users belong. The latter one refers to the set of individuals and the relationships among them. The most relevant elements of the Organizational context are the following ones:

Pre-conditions: 1. Some users need to be on the move while performing their work for the activity. 2. The activity goal is known.	
Mobility type	What kinds of mobility need to be supported (wandering, traveling, visiting)?
Mobile/coupled	Do users need to be on the move and highly connected while interacting with other people?
Mobile/uncoupled	Are some mobile users autonomous? Do they work in parallel?
Communication	What communication mechanisms are needed, according to the group members interaction? Do they require a special infrastructure?
Coordination	What requirements does the activity need for coordination? Does the activity require off-line work situations?
Criticality	How urgent is to achieve the activity goals? How important is the activity for the user?
Duration	What is the criterion to terminate the activity? How long is the activity?
Post-conditions: 1. A general characterization of each activity requiring mobile support is known. 2. A preliminary requirements specification regarding communication and coordination has been achieved.	

Table 3. Activity context elements

Organizational structure (rigid/flexible): The organizational structure will influence the group needs for coordination and control policies. A rigid organization requires formal coordination with strict control, but flexible organizations must quickly react to environmental changes by allowing group members to engage in unplanned negotiation and interaction. Although an organization may have defined a formal structure, the way people actually works may not conform to this structure. This way of working rather than the official structure should be the target of application analysis and design. Some of the affected group design elements could be: session management, floor control, data dissemination, message delivery and information privacy.

Collaboration policies/rules/norms/conventions: Every organization develops a series of social protocols, policies, rules and norms that regulate its workflow. It is important to identify which are the social rules that may be relevant for the intended application. Besides, the consequences of modifying or exploiting such rules should be carefully considered [29]. Table 4 presents some questions for understanding organizational context. This analysis must be carried on for each activity or use case identified in the previous phase. Group context elements must also be considered (Table 5), as well as Physical context elements (Table 6).

Pre-conditions: 1. The target organization is identified. 2. We know the formal and informal previous context (social context).	
Organizational structure	How flexible is the relevant Organizational structure (rigid/flexible)? What formal coordination strategies are available?
Collaboration policies/rules /norms/conventions	What policies/rules/norms/convention are developed by the organization for performing the work?
Post-conditions: 1. We know the structure of the organization. 2. We know the policies/rules/norms/conventions the organization has set up for working.	

Table 4. Organizational context elements

The analysis done with the elements of Table 4 let developers situate each activity in the Organization. Group context elements must also be considered (Table 5), as well as Physical context elements (Table 6) in order to complete the Analysis phase.

3.2.2 Group Context

We are interested on discussing the group context elements relevant to guide the application analysis and succeeding design. Some of these aspects are the following ones:

Group size: Group size matters. Research in groupware has pointed out the importance of group size for the success of the coordination, communication and collaboration strategies. Most groupware design elements [16] will be affected by the group size.

Roles: An appropriate identification of roles will help developers to design useful applications. Otherwise, the collaborative mediation process could not be well-supported. Clearly it may have a meaningful impact on the group performance. Different roles will have distinct information access privileges and functionalities in the intended application. Roles are associated to activities and thus, it is possible to start considering the resources needed by such roles, in particular, number and type of mobile devices.

Group structure: The relationships among roles will define the group structure. An understanding of the group structure and the relationship between it and the organizational structure could be useful to design the interaction policies to support collaboration. Particularly, in hierarchical organizations it is relevant to analyze the position of the group members in both organization and group structures. If the group structure does not follow the hierarchy established by the organizational structure, strategies for conflict avoidance and/or participation encouraging should be required.

Demographics: It is also important to take into account the users' characteristics, e.g., their age, gender, race, and language may influence the application design. Usability of the application will probably be improved when considering this context element. Special support might be required for disabled people; ad-hoc design for children or a specific language and icons for technical communities may be needed.

Pre-conditions: 1. We know the activities to be supported by the mobile devices.	
Group size	How many members does the group have?
Roles	What roles are present in the group? What are the attributions, responsibilities and requirements of each role?
Group structure	What are the dependence relationships among the roles (control and responsibilities)? Does the group structure keep the hierarchy of the organization?
Demographics	Are there features requiring special consideration for the interaction design (disabilities, children, senior citizens, language, etc.)? Are the demographics of the Organization significant? What relevant characteristics do group members have?
Post-conditions: 1. We know the roles structure and the characteristics of each one. 2. We know the privileges for information access. 3. We know some restrictions for the intended application look-and-feel. 4. We know some restrictions for the HCI policies to be adopted. 5. We know – approximately – the type and number of mobile devices to be required by the users.	

Table 5. Group context elements

Table 5 lists the Group context elements. Likewise the Organizational context analysis, the work to be done refers to situate the activity in the particulars of the group it will support.

3.2.3 Physical Context

Physical context is extensively researched in context-aware and ubiquitous applications [13, 21]. It considers the physical conditions surrounding each collaborator when he/she interacts or carries on a portable device. Note that a typical user will be moving from one scenario to another one and this implies the physical conditions may change. Study of the physical context provides then useful background information to choose the best mobile devices for each scenario [18]. It restricts the architectural design mainly in terms of technological support and HCI strategies. The main concerns on this subject are listed below and the relevant questions are presented in Table 6.

Physical space. This element represents the available space for deploying and operating the collaborative mobile application. The smaller/less comfortable/less stable the physical available space is, the less likely is to use large or heavy computing devices.

Environmental conditions. Physical conditions such as noise, light, number of people around and distracting factors also impose restrictions over the type of user interface to be used for interacting with the collaborative application [39].

Communication support. As users are able to move and change locations, they may arrive at places with unreliable communication support or no communication at all. It depends on the geographic areas where users perform their activities.

Safety and privacy. These are two important context elements to consider during the application design in case of mobile applications being used in public spaces. Handheld devices are specially appropriate for use in public spaces [13, 25, 39].

User location (positioning). Traditionally in groupware, it refers to users' location within the virtual environment and it is known as location awareness. Current technology lets users locate the partners in the physical world. The relevance of this information will depend on the nature of the activity. In applications where parallelism and users' mobility prevail, e.g., users may want to know each other location for planning encounters.

The context elements listed in Table 6 situate an activity in the expected physical environment in which it will be carried out. These elements have been traditionally well studied in general, but they should not be overlooked for specific activities.

3.3 Phase III. Architectural Design

The goal of this phase is to create the architectural design of the solution by considering the non-functional requirements and design restrictions identified in the previous phases. Next, the contexts to be analyzed during this phase are presented.

Pre-conditions: 1. We know the activities to be done. 2. We know the roles needed to carry on the activities.	
Physical space	What physical spaces will be used? Is there enough space for an operator to comfortably manipulate the devices?
Environmental conditions	Is there going to be adverse environmental conditions (weather, temperature, humidity, smoke, noise, etc.)? Do these conditions make operation of the devices difficult?
Safety	Is there going to be unsafe work conditions (hazardous, dangerous, or uncomfortable environments)?
Privacy	Is there going to be information with various privacy levels? Will the operator be located in places where information must be hidden from other people (curious, spying or interested looks)?
User location (positioning)	Is it important to know the physical location of collaborators?
Post-conditions: 1. There is some information useful to choose the best mobile device for each scenario. 2. Scenarios for operators to co-work are known.	

Table 6. Physical context elements

3.3.1 Technological Context

The analysis of the previous contexts determined the requirements to be accomplished by the mobile devices used to support each activity. The technological context establishes a way to match such requirements with the features of the available computing devices. Different activities could require to be supported by different mobile devices. The match can be done analyzing the following context elements for each available device:

Power supply. The activity duration is in direct relation with this context element. The analysis of this element helps developers identify if the power autonomy of the selected mobile device is enough to support each activity.

Communication capability. This context element represents the availability of networking infrastructure in the work scenario. Networks do not need to be always available and yet, it is possible to have mobile devices for collaboration since people interact asynchronously until an active network access point is reached. In this case, data synchronization may be needed. On the other hand, it should be analyzed if the selected mobile devices are able to work under this communication scenario. The communication bandwidth that is possible to get for supporting the activity should be studied.

Readiness to use. A mobile device may need short start-up time, e.g., when users have little time periods to carry out work or when quick reactions are required.

Transportability: It is important to identify those activities requiring mobility and to estimate the effort the users are able to spend while transporting the devices. For the case of users with a high degree of mobility (e.g., traveling salesmen, nurses in a hospital and children in an outdoors educational environment), issues such as device weight and size may acquire high relevance.

Computing power. Once developers understand the activities requirements, it is possible to estimate the required computing power (processing and storage capacities) for each one. Based on that, more than one device type can be selected to support activities with different requirements.

Once the list of candidate mobile devices has been established, it is important to analyze compatibility if the selected devices are heterogeneous. Incompatible devices will require additional effort when building the applications especially concerning communication protocols and data formats.

Technological context and HCI context become now relevant for this phase of the application development. Information obtained in the previous phases should be useful for analyzing these contexts. Questions in Tables 7 and 8 may be used to make the corresponding design decisions.

3.3.2 Human-Computer Interaction Context

The activities may require human-to-human interactions. It then becomes necessary to design an HCI strategy in order to support them. This strategy will be constrained by the features of the chosen mobile devices. Some elements of the HCI context that should be considered are the following ones:

Visualization. This element represents the activity needs for data display and manipulation. Typically the screen size and resolution restrict the capability to create usable user interfaces. Since a mobile device screen size is usually small, its graphical capabilities, resolution and number of colors gain importance. In some situations, user interfaces convey complex information (e.g., a shared whiteboard) while people are engaged in several activities at the same time. In other cases, a small text message will be enough for the application to function properly. In addition, screen size requirements are related to the minimum amount of information the user needs to do his job well. Applications with large visual representations require large screens such as notebooks' screens. Although handheld devices have been criticized in the literature for their small screens [18, 25], recent visualization techniques have improved the capabilities of these devices to display graphical/detailed information [6].

Data input. This element represents type and rate of data input required by the user to do each activity. Some of the typical data input devices are: keyboard, handwriting devices, pointing devices, microphone and video-camera. PDAs

Pre-conditions: 1. We know the requirements involved in each activity. 2. We know the available mobile devices to be considered.	
Power supply	What is the elapsed time required by the user to carry out the activity? Does the location where the activity will take place have power outlets? What is the autonomy of each available mobile device?
Communication capability	Does the physical environment provide communication infrastructure when needed? What communication bandwidth is required to support the activity? What type of communication capabilities the mobile devices have (protocols, bandwidth, communication infrastructure such as infrared, Wi-Fi, RJ-45, Bluetooth, etc.)?
Readiness to use	How quick should the application be ready to use when needed? How long is the start-up time of mobile devices?
Transportability	How much mobility is required to carry out the activity? What situations require mobile device transportation? How comfortable is to transport the device for the user?
Computing power	Which is the estimated computing power required to support each activity (in terms of processing throughput, storage capacity)? Which are the storage and processing capabilities of the available mobile devices?
Post-conditions: 1. We know the preliminary list of available mobile devices that can be used to support each activity.	

Table 7. Technological context elements

and mobile phones use pen-based data input, which is slow, but also useful to support short annotations [12, 38]. Notebooks and tablet PCs are the most appropriate devices to support data intensive processes using the keyboard. The input process of other data types, such as image, video or audio, is operatively similar for any kind of mobile computing device.

Multimedia capabilities. This element represents the activity needs for multimedia information support. The need may come from either the type of input/output (e.g., pictures) or the type of user/action being assisted (e.g., a child, complex data).

Usability. User interface usability and ergonomics are relevant issues in mobile scenarios, especially due to the mobile devices reduced interaction features. This is particularly important in case of some organization demographics (e.g., children) as well as high application criticality (e.g., emergency calls) and certain users physical conditions (e.g., in dark scenarios).

User multitasking. People may need to perform more than one cognitive task simultaneously. For example, an application designed for traveling salesmen may require users to walk, talk and use the collaborative system at the same time. The design of the HCI mechanism will be influenced by this situation.

Interaction privacy. This context element refers to the privacy a user needs when performing an activity. It has a direct relation to the input/output mechanisms provided by the device and the intended application. For instance, the distance between a user and a handheld device screen during the interaction is smaller than the distance between a user and his notebook or tablet PC screen; thus, developers should worry more on privacy concerns when the application uses large screens rather than small ones.

There is a mutual relationship between the technological and HCI contexts. A matching solution between these two forces should be found. Sometimes using several types of computing devices (e.g. laptops, PDAs and smart-phones) to support an activity execution requires different system implementations (application modules). In such cases, it would be interesting to try to unify the technological support in order to reduce the number of different implementations of a same groupware system. The analysis of the technological and HCI contexts is useful to determine if that unification is possible.

Once this last context has been considered (Table 8), the developers have completed all the phases proposed in the framework, as illustrated in Figure 1. At this point, developers have a comprehensive view of the intended system, a list of activities that require mobile support and compose the collaborative task, a list of non-functional requirements and design restrictions for such activities. The mobile devices to be used must be chosen as a result of the process. Besides, the developers know which software modules should be built to support each activity. It should be noted that the activities not requiring mobile support are studied not according to this framework but to a normal software development process. Nevertheless, some of them will benefit from the specified contexts above.

4 APPLYING THE FRAMEWORK

This section presents the application of the framework to a real case. The example is a process to develop a groupware system supporting decision-making activities for search and rescue after an extreme event. The types of emergency situations considered were natural, hazardous and intentional extreme events, such as earthquakes, chemical spills, fires and terrorist attacks. The obtained software product followed the Chilean National Regulations for urban search and rescue [1], which are used in middle-size or large emergency situations in the country. Next sections describe the phases executed during the system development.

Pre-conditions: 1. We have a preliminary list of available mobile devices that can be used to support each activity. 2. We know the activities to be supported.	
Visualization	Does the activity need to show complex information (e.g., pictures, videos and animations)? Can the mobile devices display the required type of information? Is the screen size and resolution good enough for implementing usable interfaces?
Data input	Does the activity require the user enter several types of data (from keyboard, sensing devices, cameras, etc.)? Does the activity need input of large amounts of information? Is the available mobile device able to handle the type and amount of required data input?
Multimedia capabilities	Does the activity require animations, pictures, sound or movies? Do the available resources (memory, processing, bandwidth, etc.) satisfy the needs to manage multimedia requirements?
Usability	Are user interface usability factors particularly important to perform the activity? Are there device ergonomic factors relevant for its operation?
User multitasking	Does the activity require the user do simultaneous cognitive tasks while using a device? How much attention does the device require for operating it?
Information privacy	Does the activity require management of private information? In such a case, is the activity performed in public spaces? Is the device appropriate to handle private information in public spaces?
Post-conditions: 1. We have the list of available mobile devices that can be used to support each activity, considering this and the previous contexts. 2. We know the usability restrictions related to the user interfaces design.	

Table 8. Human-computer interaction context elements

4.1 Conception Phase

The conception phase started with the analysis of the social context and collaborative task context (Tables 1 and 2). The social context considered a flexible task force able to organize itself on the fly, depending on the available resources in every emergency situation. The organization typically is characterized by a loosely-coupled link among agencies, such as police, firefighters, medical personnel and government offices. Typically, these agencies involve rigid hierarchies and do not mutually collaborate [33], but it is important that shared information can flow among them. We discovered every worker should be autonomous and able to share information on an ad-hoc network thanks to this characterization. These sharing capabilities must be available regardless of people's affiliation.

A National Emergency Plan establishes rules and regulations (previous formal knowledge) to coordinate the effort of these agencies, and the personnel has been trained in that subject (Table 4). However, it requires communication support and a real agreement among involved agencies in an emergency situation. It means inter-agency communication must be implemented. Furthermore, we cannot assume inter-agency coordination activities be performed. On the other hand, it is known improvisation is the first option for first responders whom are not receiving orders from the disaster managers (previous informal knowledge). In addition, first responders have a mix of individualist and collaborative behavior; therefore, support to first responders during improvisation should be seriously considered in the software design.

Initially, it was assumed most people were able to use basic IT resources to support their work (Readiness to use IT – Table 1). These resources involved desktop PCs, laptops and PDAs. The reality was, however, most of them were well-trained to use mainly radio systems and information on a map (work practice tools). By contrast, many of them were unable to use handheld devices to operate the system.

The collaborative task to be supported by the system was a distributed group decision-making process. This process occurs in parallel and at several abstraction levels during a search and rescue activity (Table 2). In order to do that, the system must let people communicate to each other, coordinate their activities and share information.

It is possible to identify at least three main activities as part of the collaborative task considering the collaboration goal, the social contexts and the National Emergency Plan (Table 3 and 4):

1. making low impact decisions in the fieldwork and update shared information,
2. making global decisions and guide the resistance/recovery process, and
3. provision of advice and technical information to support decision making.

Typically, fieldworkers make local and short time decisions, meanwhile emergency managers make broad scope decisions to coordinate the fieldwork teams. The two types of decision-makers work under pressure in the disaster area and require mobility. Emergency managers are supported by remote experts providing advice and important technical information to guide the mitigation process. Remote experts usually work with low pressure and they do not require mobility (Table 3).

Medical personnel who usually support the search and rescue process were not initially considered. What applications modules should be developed to support the included activities? What restrictions and non-functional requirements should be considered for each application module? Answers to these questions can be found following the next phases of the framework.

4.2 Analysis Phase

Every activity identified in the previous phase is considered as a use case characterized by the context elements presented in Table 3. These context elements include non-functional requirements and design restrictions.

The decision-making process and data capture done by first responders are considered to illustrate the analysis of the activity context elements. This is a mobile/coupled activity, highly coordinated, which requires wireless communication because of the user mobility. The criticality of such activity is variable depending on several contextual elements. Therefore, it would be wise to consider this activity as critical, because it is the most demanding collaboration scenario. In addition, the National Emergency Plan considers people working in 6–8 hours shifts depending on the emergency type. By analyzing the work scenario it was possible to choose an appropriate software solution running on handheld devices fitting the requirements. However, the limited battery life of these devices pushed software designers to implement a battery aware solution, and to consider battery exchange during a work shift.

This decision-making activity, like other activities making up the collaborative task, involves organizational, group and physical contexts. The organizational context includes the hierarchies inside each agency and the way these people behave. In this case, developers knew not all agencies were open to collaborate with their partners. However, it is expected they adhere to the National Emergency Plan (which has minimal collaboration requirements).

First responder teams from the same organization are able to work collaboratively (group context). Every team has a chief who is in charge of 10–30 fieldworkers (Table 5). The teams hierarchy considers a manager for every 10 subordinate groups approximately. Moreover, shared information should be distributed and maintained in order to support the decision making process. Fieldworkers have to use small mobile devices because of the high mobility required by the fieldwork. Managers and remote experts are able to do stationary work.

On the other hand, the physical context where first responders carry out their activities is typically highly dynamic, stressful, dangerous and uncomfortable (Table 6). It is possible to determine additional requirements based on these context elements, such as: just the chiefs will interact with the collaborative application, the interface of the application should require minimum attention and it has to be easy to use, information should be highly replicated because of the disconnection produced by the physical scenario, and the system should run on a device able to be used while walking.

Some non-functional requirements and preliminary design restrictions can be established considering these context elements, e.g.,

- shared information interoperability is required because of the participation of heterogeneous organizations,
- floor control should be flexible and its scope is on an individual organization basis,

- work sessions and operation distribution should be by agency,
- the decision making process should also be within an organization,
- provided that chaotic situations occur in the fieldwork, a rigid decision making process is not possible in such organizational context,
- a global floor control policy is required because of inter-agency coordination,
- data synchronization is required because there is shared information to be updated,
- the communication will be wireless using multi-hop information distribution because the high mobility of the first responders, and
- every node should be as autonomous as possible because the mobility of the users could disconnect them.

4.3 Design Phase

The previously identified non-functional requirements and preliminary design restrictions can be now put to use. They can be helpful to establish the type of technology to be used to support each activity and the type of interaction to occur between the collaborative application and the user. This is the first formal step towards a solution and it is part of the architectural design.

The technological support for field work activities should involve wireless communication and hand-held or wearable computing devices because of the high mobility of the users (technological context). Provided the physical environment is hazardous and hostile, the devices should be designed to be used in such environments. Furthermore, the application running on each mobile unit should be as autonomous as possible because of the high disconnection rate produced by the user mobility and physical context. It means the system has to work in a dual way: synchronously if the communication is stable, and asynchronously when the communication is unstable or the signal strength in low. Finally, the module running on the hand-held device should consider all hardware resources and usability limitations, especially the power supply [18]. Because of the activity duration, the use of extra batteries for the devices should be considered.

On the other hand, the application should require minimum visual contact between the user and the interface, because of the dynamic and dangerous physical scenario (HCI context). For the same reason, the information presented in the user interface should be rich and easy to understand. Typically, visual representations summarize information, but they require appropriate hardware resources. Besides, interactions through channels not requiring visual attention from the user should be considered, such as audio conferences. Since the users had radio systems training, the communication system could take advantage of this situation.

4.4 The CoSDRE System

Two variants of this collaborative application were developed: one for first responders and another one for managers and remote experts. Each variant of the system addresses the requirements imposed by the specific work contexts identified as use cases.

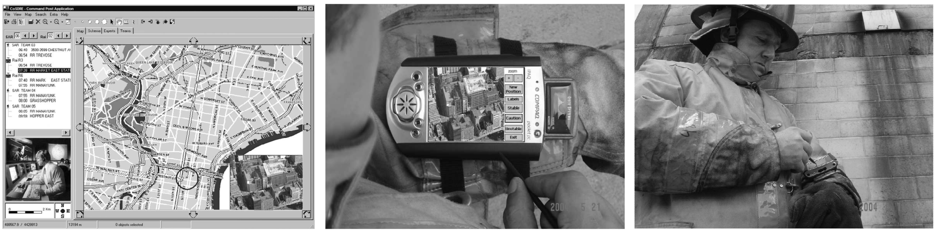
The system named CoSDRE (Collaboration Support for Disaster Relief Efforts) allows people with different work contexts to share XML information [18]. The system is a kind of collaborative GIS (Geographic Information Systems), which provides collaboration support between the command post and the remote experts as well. It also assists the collaboration between the command post and first responders inside the disaster area.

People located at the command post have usually low mobility and can work in a comfortable place, thus they can use the variant of the system that provides full functionality. This variant of the system runs on notebooks or desktop PCs, usually installed on a trailer. That application can link the information updated by first responders with areas in a map (Figure 2 a)), allowing a detailed diagnosis of the disaster scenario. In addition, it allows to assign tasks to first response teams and to keep track of the activities carried out by each team. This application has two special collaboration spaces allowing the command post to interact with remote experts and first responders respectively. These collaboration spaces also include a voice conference system to interact with first responders, and videoconference to interact with remote experts. The audio system used by first responders in the work field is similar to a traditional radio system.

It was assumed that computers at command post are able to be permanently communicated with remote experts through communication infrastructure typically installed in a truck. The work context for remote experts is similar to the one of people working in the command post.

On the other hand, first responders working in the field need to be communicated with the command post in order to send information (local decisions), receive orders and update the awareness information related to the disaster situation. The physical context for these first responders is uncomfortable, risky and the activity context involves unstable communication and high mobility of the collaborators. Besides, the interaction between first responders and the system requires navigation low data input rate; therefore, their collaborative work is done using a small variant of the system, which runs on a PDA (Figure 2 b)). That application runs on a PDA located on the arm of first responders (Figure 2 c)) and the communication support is provided through a MANET (Mobile Ad-hoc NETwork).

An experimental exercise was conducted to evaluate the system usability. The results showed the application was useful [2]. Nevertheless, not all people were able to use it provided some of them were not really ready to use IT solutions. This issue was identified when analyzing the questions on Table 1, but the answers were inconclusive since there was much uncertainty about the final users' skills. The autonomy designed for each mobile unit works well, considering the high rate of



a) b) c)

Fig. 2. Groupware system to support disaster relief efforts

disconnection detected in the exercise. The physical scenario was well characterized (Table 6) except because many rubbles in the terrain produced more disconnections than expected. The synchronization mechanisms designed to support collaboration among different agencies were appropriate (Table 5). However, these agencies requested just few synchronization operations, because the relationships among them were minimal. The collaborative work inside an agency was well carried out since it had a clear organizational structure and collaboration policies (Table 4). The collaborative task context (Table 2) allowed software designers to identify main activities and roles linked to them. Table 3, in turn, was useful to characterize each activity.

5 CONCLUSIONS

Traditional software development processes do not have a context based approach for the design of groupware applications. Lack of context consideration complicates the application adoption by users, its effectiveness and usability. This situation is highlighted when the collaborative application requires mobile support, mainly because the context of use may change while the user is working with the application.

A cause of this problem is the lack of a systematic approach for analyzing the relevant context elements that allow developers to identify non-functional requirements and design restriction to be considered in the application. In addition, such systematic approach should complement and adhere to a typical development software process.

This paper has presented a context-based framework for the analysis and design of mobile collaborative applications. The framework includes a systematic process to be applied as well. Such process should be embedded in a typical software development approach; particularly in the conception, analysis and design phases. Besides, an example of using the framework is presented and discussed.

The use of this framework allows developers to get a comprehensive understanding of the problem domain. Such understanding will provide a good insight of the prospective context where the solution will be used. In our previous experiences developing mobile collaborative applications, we fell into some design mistakes that could have been avoided using the framework. Some of these cases are mentioned below.

When developing the first response application we disregarded the senior firefighters PDA unfamiliarity. This was because developers ignored the demographics of the group members (Group context). Furthermore, the application was used in dark environments sometimes filled with smoke and the built-in power supply was quickly consumed. Some portable devices were able to provide enough luminance for operating the interfaces, others had enough autonomy battery life, but in the end not all devices were able to support the entire activity. These problems occurred because we ignored the environmental conditions (physical context), the activity duration (activity context) and the power supply (technological context).

When developing a CSCL application for children, we disregarded the child's IT terms unfamiliarity (the login-password concept) [19]. Again, the problem happened because of ignoring the demographics of the group (group context). Moreover, the developed activity had to be canceled due to the wireless network service intermittence. As the occurrence of this situation was ignored, we were not prepared for resuming the activity, and thus the activity had to be started again from scratch. The cause was a poor understanding of the communication capability (technological context). Both examples illustrate the benefits of using the proposed framework for supporting the analysis and design of collaborative mobile applications.

How comprehensive is the framework? A serious effort has been done to cover all typical situations. This is based on the development of several collaborative mobile applications for very different types of customers: besides the case described in this paper, we have developed two other systems reported in [18]: a system for collaborative authoring and one for supporting the recording of television series. A fourth case, a CSCL application for children has not yet been reported. We also have participated in other development efforts of a smaller scale. Although we know that the context categories are infinite [31], the discussed contexts have shown to be useful to support the development of this kind of applications. The framework perhaps could be useful to support the development of non-collaborative mobile software applications. Besides, the framework could be adapted to assist the analysis and design of stationary groupware applications. These extensions are the subject of future research.

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