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A Conceptual Framework for the Design of Geo-Collaborative Systems

PEDRO ANTUNES
LaSIGE/Department of Informatics, Faculty of Sciences of the University of Lisboa, Bloco C6, Piso 3, Campo Grande, 1700 Lisboa – Portugal
(E-mail: paa@di.fc.ul.pt)

PAULA ANDRÉ
LaSIGE/Department of Informatics, Faculty of Sciences of the University of Lisboa, Bloco C6, Piso 3, Campo Grande, 1700 Lisboa – Portugal; INETI – Instituto Nacional de Engenharia, Tecnologia e Inovação, Estrada do Paço do Lumiar, 22, 1649-038 Lisboa – Portugal
(E-mail: Paula.andre@ineti.pt)

Abstract

Geo-collaborative systems address the computational support to situations where people are working in different locations, gathering geographically-related data in the field and sharing knowledge. We propose a conceptual framework identifying the design issues that fundamentally set the stage for eliciting the requirements of geo-collaborative systems. The conceptual framework has five elements: places, teams, tasks, artifacts and geo-referenced knowledge. We also highlight two important relationships between some of these elements: (1) a task-artifact relationship, related with the need to increase the organizational decision making abilities through concerted efforts; and (2) an artifact-knowledge relationship, related with the need to support mechanisms for jointly understanding geo-referenced data. The conceptual framework was applied to the development of a groupware tool aiming to increase the productivity of the geological mapping process followed by a national agency with competence in this area. The paper describes in detail how the conceptual framework influenced the groupware design. The obtained results indicate that the framework can focus the designers on the human aspects of geo-collaboration and guide them through the initial design stages.

Key words: geo-collaboration, geo-collaborative systems, geo-informatics, groupware, sensemaking

1. Introduction

Geo-collaboration is a complex working situation, characterized by multiple experts working in different places in a coordinated or concerted effort (Nunamaker et al. 1997), gathering and interpreting geographically-related data, and mapping it into meaningful representations. In contrast with the traditional geographical mapping processes, the fundamental ideas behind the development of geo-collaborative systems are to minimize the number of visits to the field necessary to obtain consensus on specific geological elements from experts in different fields; and simplify the collaborative decision process involved in geographical mapping.

Research in this area has primarily focused on technical issues such as infrastructure support, remote information access and integration of diverse data with geographical references. We argue there is a lack of knowledge about many non-technical issues vital to geo-collaboration, disentangling the complexities of the work settings, collaborative activities and decision-making processes, as well as their relationships with geographically referenced information. Consequently, this paper aims to accomplish two fundamental purposes:

- Identify and characterize several human factors involved in geo-collaborative systems;
- Provide the systems designers and technology developers with a roadmap for eliciting the user requirements of geo-collaborative systems.

We codify the roadmap in the format of an exploratory conceptual framework. According to Miles and Huberman (1994), an exploratory framework provides general constructs identifying events and phenomena of interest to start inquiring about the work context, the human roles and activities, and the required system functionality. As a map, an exploratory conceptual framework identifies *what* information is of most interest to designers and developers, bounding their relationship with the other stakeholders, since some data discrimination is necessary. Integrated with a good plan, an exploratory conceptual framework also guides the design process, identifying *how* user requirements may be gathered and applied. In this research we integrate the conceptual framework with the contextual design approach proposed by Beyer and Holtzblatt (1998) with the purpose to supplement the recommendations about *what* information to elicit from stakeholders with recommendations about *how* to design from that information.

The conceptual framework was applied in a real-world case involving the production of geological mapping for a national agency named IGM (Geological and Mining Institute, recently merged with INETI). This research was relevant to IGM because they were faced with productivity problems with geological mapping. From our point of view, the target organization was extremely relevant to evaluate our conceptual framework because their work context was completely aligned with the characteristics of geo-collaboration.

The geological mapping process at IGM is comparable to setting together the pieces of a jigsaw puzzle, having several collaborative activities distributed in time and place aiming at getting different pieces of information together in a coherent way. When experts have doubts, they have to collaborate with other specialists in specific areas such as structural geology, paleontology, petrology and sedimentology. This collaboration frequently implies one or more visits to the study area, sometimes in remote places with difficult access. Therefore, the geological mapping process at IGM can be expensive and time consuming (for instance, studies in the Azores islands are very expensive and time consuming, being scarcely populated and located in the middle of the Atlantic). Sometimes a geological mapping process at IGM takes more than two years for completion.

Using the framework, we were able to design and develop a geo-collaborative system to optimize the geological mapping process at IGM. We will describe the role of the conceptual framework in shaping the design decisions that resulted in the implemented geo-collaborative system.

This exploratory research action provides several insights about geo-collaboration and contributions to the design of geo-collaborative systems. The most significant design contributions are related to artifacts and emphasize that designers shall explore the potential of artifacts to support concerted work and sensemaking activities.

This paper is structured in the following way. In the next section we refer other research related with geo-collaboration. In the following section we describe in detail the proposed conceptual framework. Then, we describe the case study, explaining how we gathered data from the IGM experts and our interpretation of the work activities related to the geological mapping process. We complement this description with a detailed explanation of the design and implementation phases that followed interpretation, and a brief report on two prototype evaluations done with IGM experts. Finally, we discuss the benefits offered by the conceptual framework, draw some implications for design and present the conclusions of this work.

2. Related Work

2.1. Geo-collaborative systems

Spatial Decision Support Systems (SDSS, (Nyerges et al. 1997)) is one research area dedicated to study the combination of GIS with Decision Support Systems (DSS). Following the perspective that Group Support Systems (GSS) are a specialization of DSS, there is likely a possibility of combining SDSS and GSS, a technology arena that has been coined Collaborative Spatial Decision-making (CSDM, (Densham et al. 1995; Nyerges et al. 1997)). Armstrong (Armstrong, 1997; 1994; Armstrong and Densham, 1994) discussed the potential benefits of using groupware in this context, emphasizing the need to support shared graphics and group modeling activities.

The technological combination of GIS and workflow management systems has been studied by Holowczak et al. (2001) and Coleman and Li (1999). Medeiros et al. (2001) also developed a technological infrastructure integrating GIS, workflow technology and GSS.

Another research arena addresses information structuring in mobile settings. Open GIS (Gardels, 1997) and COPA (Touriño et al., 2001) integrate scattered information with geo-referenced information. Hope et al. (2000) studied the access to remote databases by field workers, while Zhao et al. (2002) analyzed the infrastructural requirements for mobile GIS. Pundt (2002, 2000) studied the visualization of data acquired with mobile GIS. All of these research projects do not directly address geo-collaboration but explore basic features to support such functionality.

Note also that none of the research mentioned above addresses human factors in geo-collaborative systems. In this area, we account for Rauschert et al. (2002) and Coors et al. (1999), who studied user interactions with multimodal and tangible GIS interfaces. Both research studies addressed single display configurations. In the same line, we also cite several developments in synthetic collaborative environments for geographic visualization (geo-visualization) (Grønbæk et al. 2002; Manoharan et al. 2002; MacEachren et al. 1999).

Two other projects currently being developed (Nusser et al. 2003; Pinto et al. 2003) address human interaction with digital geo-referenced information in fieldwork. These projects are studying the integration of contextual information (photographs, etc.) with geo-referenced information, and state that are experimenting several ways to navigate through information gathered in the field. Only preliminary information is currently available on these projects.

Our perspective of the outlined research is that, although we have many studies combining GIS with DSS, GSS, workflow, single display groupware, virtual worlds and mobile GIS, the problem area described in this paper is still open. There is insufficient information about the human factors influencing the support to geographically-related collaboration in the field.

2.2. Conceptual frameworks for geo-collaborative systems

Several well-known conceptual frameworks have been proposed in the GSS field, e.g., (McGrath 1984; DeSanctis and Gallupe 1987; Nunamaker et al. 1991). These frameworks, while being generic, do not explicitly include a key concept in geo-collaboration: geographical references play a central role in tying information together (Mackay, 1999). Nyerges et al. (1997) contrasted various generic GSS frameworks with GIS requirements to propose a group-based GIS framework where geographical referencing is made explicit. This framework is specific for the transportation context.

In addition, we observe the notion of place, which is a fundamental factor for most cited GSS frameworks, captures a significantly different context: less tied to group proximity (e.g., face-to-face or distributed (Nunamaker et al. 1991)) and more related with the users' mobility in space while capturing geographical referenced data. Oulasvirta et al. (2003) proposed a framework focusing on the mobility issue. The framework provides guidelines for eliciting mobile technology requirements, with an emphasis on innovation. In a later development, Oulasvirta and colleagues (Oulasvirta, 2004; Tamminen et al. 2004) propose a broader approach for discovering new design ideas for "beyond the desktop" technology, based on context-awareness. In any case, GIS was beyond the scope of these approaches.

Our perspective is that a new framework is necessary, combining the characteristics of GSS and GIS and explicitly tackling the fundamental role of geographical references in mobile collaborative contexts.

3. Conceptual Framework and Design Process

Considering the lack of knowledge mentioned in the previous section, it was clear from the beginning of this research that we were assembling an exploratory framework. The framework is bounded by two major requirements: it has to be open for exploring and interpreting human factors in geo-collaboration, thus requiring relatively abstract elements and under-specified constructs; and it has to link them in a purposeful way. At this stage our major purpose is to set the boundaries for inquiring about geo-collaboration and ascertain guidelines for geo-collaborative systems design.

Our hypothesis is that the framework facilitates the design process, providing a roadmap to the designer, highlighting paths to the right solutions but with significant decision latitude. Consequently, the validation of our hypothesis will not consist in the verification of the

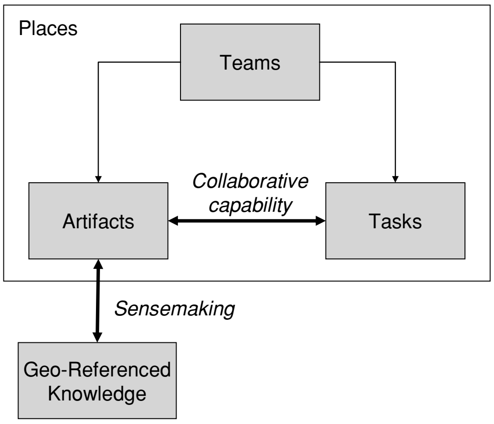

Figure 1. Conceptual framework.

correctness of the framework, but rather in the appreciation of its ability to supply the designers with successful guidelines.

The proposed conceptual framework is shown in Figure 1. It was derived from practical experience designing collaborative technology for mobile situations (e.g., (Costa and Antunes, 2002; Costa et al., 2002)) using user-centered design (UCD) approaches (e.g., (Beyer and Holtzblatt, 1998; Carrol, 2000)). The four basic framework elements are teams of people, tasks, artifacts and places. Teams manipulate artifacts to accomplish tasks in certain places. This combination of elements is sufficiently abstract to afford the most common spatial arrangements that we find in groupware, ranging from one team working in the same place to several teams working in different places. The same argument applies to artifacts and tasks, were we may consider having artifacts/tasks residing in a single place or distributed through different places. We assume these elements are consensual in the UCD and groupware fields, so that no further considerations are necessary.

In contrast, the relationship between artifacts and tasks, noted by the "collaborative capability" designation, deserves further considerations. The notion of collaborative capability was developed by Nunamaker et al. (2002). It identifies several categories of increasing ability for successful creation of meaning, ranging from the individual, collective and coordinated to the concerted creation of meaning. The theory is that organizations will increase their potential to create value by increasing their levels of collaborative capability.[1] We realize this theory has an immediate impact in the geo-collaboration field, because work activities and processes are significantly affected by geographical constraints (e.g., visits to the field cost time and money), and thus there may be an opportunity for increasing the organizational effectiveness. Departing from the theory, we draw an implication for design: the development of shared artifacts, supporting concerted tasks, should be preferred to the development of individualized artifacts, so that work processes become independent of geographical constraints.

Another element we introduce in the conceptual framework is designated "geo-referenced knowledge." We regard the manipulation of artifacts, in the context of

Figure 2. Field worker taking measures with the compass.

geo-collaboration, not an end in itself but a mean to construct/augment shared knowledge about the earth surface and objects found on it. This shared knowledge is necessarily tied to geographical references and mediated through artifacts. We may characterize the relationship between artifacts and geo-referenced knowledge as sensemaking. Sensemaking has been defined as an ongoing process aiming to create order and make retrospective sense of what occurs (Weick, 1993). It has also been associated to collaboration (Larsson, 2003) and preliminary decision-making activities like "understanding the situation" or "getting the picture" (Hasan and Gould, 2001). We argue sensemaking precisely captures the fundamental nature of geo-collaborative activities: people with different expertise working together to grab geographical information from various sources and places into a meaningful representation. As the sensemaking theory posits, the outcomes from geo-collaborative activities result from "thinking by doing" (Weick, 1993), since problems and solutions are highly context dependent (places, paths, persons, expertise, available experts, available time, occurrences, etc).

The presence of this element in the conceptual framework introduces one more implication for design: artifacts must support the mechanisms required by sensemaking, such as searching, browsing, visualizing or summarizing geo-referenced information. Note that we consider geo-referenced knowledge independently from place, unlike artifacts. Designers may take advantage from this characteristic of artifacts to extend sensemaking support with place-sensitive functionality.

Addressing the previously expressed requirement that the conceptual framework should provide guidelines for geo-collaborative systems design, we turn our attention to the design process. We adopted the contextual design process, briefly summarized in the following steps (Beyer and Holtzblatt, 1998):

1. Data gathering phase, using a mix of ethnography (observing work in the usual work environment) and interviews (using a master-apprentice style).
2. Modeling five aspects of work: flows (of information between users), sequences (of low-level actions performed by users), artifacts (produced and manipulated by users), physical and cultural environment (constraining work).
3. Innovation from the models. The deeply understanding of the work context expressed by the five models suggests new ways to accomplish work.
4. System design, focusing on the coherence of both the user experience and user interface.
5. Prototyping. Low-fidelity prototypes (based on paper) and mock-ups are created with the purpose to communicate the design to the users.
6. Validation with users. Low-fidelity prototypes are used in context interviews to gather feedback from users about the adopted design solutions.

From our point of view, the conceptual framework affords tailoring the contextual design process to the geo-collaboration context in the following way:

1. The data gathering phase may be structured around the conceptual framework elements, focusing the interviewees on the collaborative capability and sensemaking issues (how they organize themselves and make sense of scattered geo-referenced data).
2. The framework increases detail around places, artifacts and geo-referenced knowledge, thus focusing the work models on the phenomena of most interest to geo-collaboration.
3. We also suggest that attention to collaborative capability and sensemaking will raise new opportunities for removing workaround activities and identifying unexplored work practices, which are characteristic of innovative design solutions (Vicente 1999).

Next, we will describe one concrete case where the contextual design process was structured according to these guidelines, and further clarify and explain the several claims made in this section.

4. The Case: Geological Mapping at IGM

IGM is a national agency responsible for disseminating information about geological, hydrological and mining resources under the Portuguese jurisdiction. One of the main tasks attributed to this agency is to produce an inventory of geological resources in the form of geological maps. This specific task is the focus of our case study.

To build a general knowledge about the geological mapping process, we started by gathering data from varied sources, including IGM experts and internal documentation. The conceptual framework shown in Figure 1 was used to screen relevant information about the following thematic areas: teams participating in geological mapping, assigned tasks, used artifacts and work places. After this initial phase, we understood that work starts in the office, where all information available at IGM about a particular region is collected and analyzed. This information includes different types of maps (topographical and geological, in different scales), scientific data (geo-chemical, geophysical), bibliographic references and notes from previous projects done in the same region. Then, work continues in the field, where the field team obtains missing geological data. Finally, work is completed in the office, where field data is analyzed, organized and consolidated in a geological map. Most frequently, the initial consolidation steps are accomplished individually, while the later steps require collaboration with other experts.

Of course, this is an idealized work process, which assumes that no problems appear. According to the estimates we obtained from IGM, a typical geological mapping process takes about 2 years to complete, as a consequence of several visits to the field, multiple activities in the office and gap periods. Several critical incidents concur to increase the process complexity: (1) bad initial planning or initial data, reducing the effectiveness of field work; (2) the occurrence of doubts when analyzing geological data in the field, due to lack of experience or knowledge about the designated area; (3) the emergence of doubts in the office, because the data obtained in the field is equivocal and cannot be consolidated; (4) the occurrence of conflicts between experts, which can only be resolved by sending someone to the field to confirm data; and (5) the concurrent execution of multiple geological mapping processes, which cause management and planning difficulties.

During these initial research steps we were able to analyze the final artifacts resulting from the geological mapping process, but were not able to discern how knowledge was collectively utilized to construct these artifacts; neither how artifacts were manipulated by teams. We therefore decided to gather that information directly from the IGM personnel, using the combination of ethnography and interviews suggested by the contextual design approach.

Based on the conceptual framework, we formulated a list of research questions to be used in our interviews. Our aim was to analyze in detail two different episodes: (1) field work; and (2) data consolidation in the office. The first episode consisted of a real working scenario: the geological mapping of map nr. 288 (inland, about 200 Km north-east of Lisbon, Portugal), which was ongoing at IGM when this research started. This was a full day episode involving one person from IGM who was highly proficient in the data gathering process, having many years of experience.

We requested the expert to think aloud and explain what he was doing, and asked the prepared research questions whenever appropriate. The used instruments included a tape recorder, paper, pencil and photographic machine. By the end of the day the data collected was summarized and validated with the source.

Concerning the second episode, addressing data consolidation in the office, a different approach had to be settled. We realized that the geological mapping process is carried in the office in parallel with many other activities and scattered throughout many weeks. Therefore, the interview technique was used instead of observation. Several interviews were dispersed over a period of three weeks.

All data obtained in the field was later transcribed to text and coded. The following list of codes, derived from the conceptual framework, was used to classify that data:

- Artifacts – Topographical map, geological map, field book, overlay, compass, log, hammer

- Knowledge – Contextual, localization, description, drawing, doubt, attitude measure, meteorological
- Teams – Behavior, doubt
- Tasks – Study, observe, walk, measure, associate, use hammer, draw, interpret, identify, conclude, search, analyze, take photo

The quality of the obtained results was reviewed by experts from IGM, including the one that participated in the first episode. The representativeness of the results was also discussed, considering that the data was gathered from two single episodes. Some additional clarifications of the geological mapping process were obtained at this stage, in particular to understand specific details about the several drawings produced in the field. These interim results demonstrated the ability of the conceptual framework to guide the data acquisition phase.

4.1. The first episode

We will now discuss the first episode in more detail, starting with a brief presentation of the outcomes, followed by a clarification of the contributions offered by the conceptual framework. The field team may have several elements, although the most frequent composition is one element. Field work begins with the team trying to locate themselves in the map and in the territory, using a compass or GPS and any conspicuous points that may be referenced in the map (a church, water line, elevation, etc., see Figure 2). Next, the team looks for any spot heights that may give hints about the zone's geomorphology. For instance, spot heights can give an indication of hard formations like Quartzites. Conversely, a water line can hint a zone of geological weakness or fault. At this stage, the team annotates the map and geo-references data in the field book with everything relevant that is observed. The map and field book are two fundamental artifacts for this purpose. The map is in fact used in combination with a transparent overlay, placed above the map, where the annotations are taken (see Figure 3).

The field book stores all the information gathered in the field that is supplementary to what is traced on the transparent overlay. In Figure 4 we show a page taken from the field book, filled up with several notes, descriptions, doubts and sketches. As can be seen in the transcription below, the positioning, geological descriptions, sketches and doubts arising on the experts' heads are important to characterize field work:

(1) Position–"Map nr. 322–300 year old house"
(2) Sketch–Sketch of trust fault and orientation
(3) Doubt–"Carvalhal hill seams to be in trust fault from East-West"
(4) Description with reference to location–"The sandstone in the border of map nr. 322, in the intersection of road Mação have East-West direction and dip towards North, are frequently Micaceous"
(5) Interrogated Description–"Porphyry seem to exist in the middle of conglomerate. Are there any strata? Which have an angle: is it Pyrite in the trust fault?"
(6) Doubts about geo-referencing

Figure 3. Field worker tracing on the transparent paper overlaying the map.

(7) Doubts–“Are the minerals metamorphism derived? Being so, they have their origins in Porphyry, but are not they previous to sandstones?”
(8) Doubt–“Fault could give Hornfels?”

There are several doubts in the field notes transcribed above that might disappear with a second visit to the study area. This is the case of item (3). The clarification of this doubt may give a whole new geological interpretation of the area. Another doubt is item (7) where the expert is not sure if the found minerals are metamorphism-derived. And in that case, there is another doubt with a structural context: “but is not Porphyry previous to sandstones?” These doubts will be addressed later in the office.

While the team goes through the territory, they may use a compass to measure the attitude and inclination of the geological formations (see Figure 2). This contextual information helps confirming the geology of the area, as the same values for inclination can indicate the same formation. The experts preserve this information by tracing on the transparent overlay. Sometimes they also sketch the formation in the field book. The experts occasionally use a geologist’s hammer to identify the geology of the area. They do not only check the rock fragments but also analyze the sounds produced by the hammer striking the rock. For instance, in the specific episode that we analyzed, we observed that the Quartzites produced an acute sound, almost metallic.

Regarding our analysis of the obtained data, we would like to emphasize the crucial role of the conceptual framework in the identification of the following design requirements:

- Work in the field evolves around two fundamental artifacts: field book and map/transparent overlay. These artifacts effectively mediate knowledge production and management. This knowledge is geo-referenced, as clearly demonstrated by the field book transcript.

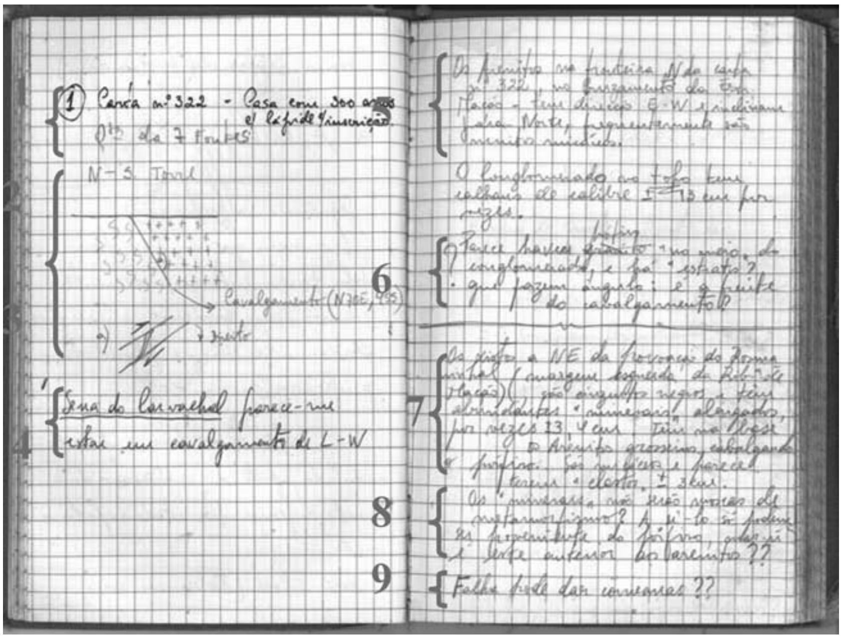

Figure 4. The field book.

- The field book is personal, signifying a reduced collaborative capability. This gives an hint that there may be an opportunity to increase the collaborative capability by sharing the field book.
- Sensemaking is problematic, because many unresolved doubts arise during field work. We note also that the geo-referenced knowledge is distributed between the field book and transparent overlay, which are difficult to co-relate. These observations indicate there is ample opportunity to develop information management mechanisms aiming to increase sensemaking.

4.2. The second episode

Going back to the office, the field team reports to the office team, typically composed by one coordinator and several experts in geology and other related fields, like hydrogeology and geophysics. The coordinator, having overall responsibility for the project, validates the consolidation process. The other office team members are responsible for searching information in their expertise areas, resolving doubts raised by the field team, discussing results, identifying additional sources of information, guiding future activities of the field team and contributing to consolidation. Whenever it is necessary, members of the office team go to the field to revise, clarify and confirm geological information related with their areas of expertise. Other times the office team requests the field team to go back to the study area in order to take further measurements.

Although the coordinator has overall responsibility for the process, it is a responsibility of the field team to promote the consolidation of the data gathered in the field, i.e. it is their responsibility to carry out the geological mapping process to success. The consolidation is hardly accomplished in one single event. Several meetings, scattered through a long period (sometimes months) are carried out with different members of the office team to address specific doubts. During this phase, the field team uses intensively the field book to recall the doubts and put them back in context: where they occurred, the sequence of events, data collected nearby, etc. Overall, data consolidation is seen by both teams as completing a jigsaw, where several pieces must be put together with the help from several experts. These outcomes, framed by the conceptual framework, reinforce the design requirements we previously identified:

- It is now clear that the geological mapping process is significantly delayed by the need to swap work between the office and the field, a situation which could be resolved by increasing the team's collaborative capability: bringing all relevant stakeholders together to resolve problems as they appear in the field or in the office.
- Field workers show difficulties reconstructing problems encountered in the field, which reinforces the observation that the field book is restricting sensemaking.

4.3. Work modeling

With the data summarized above, we proceed to the next design step. Five types of work models were specified: flow models, describing the information flows between the field and office teams; sequence models, providing details about how the team members manipulate artifacts; artifact models, describing the field book and the overlay; physical models, describing the physical characteristics where the work takes place (field and office); and cultural models, identifying the cultural forces behind the work process. Overall, we observed that the conceptual framework facilitated the model construction, because its basic elements (teams, tasks, artifacts and places) are well aligned with the selected design approach.

4.4. Design solution

The sensemaking and collaborative capability framework constructs naturally increased our attention to the field book and map/transparent overlay analyzed in the episodes one and two. These two artifacts play an important role upholding diverse geo-referenced information gathered in the field and supporting the consolidation process, when the teams complete the jigsaw to come up with a complete geological map. Based on these observations, our first design decision consisted in developing digital artifacts which could reproduce the actual field book and map/transparent overlay, while offering ample opportunities to increase sensemaking, because teams may link different data types, cross-reference information between artifacts and utilize search mechanisms.

The second design decision consisted in allowing the field team to get in contact with the office team while in the field. This was suggested by the observation, made in the second episode, that the geological mapping process is significantly delayed by the need to swap work between the office and the field. This contact mechanism should afford some flexibility getting in contact with the office team, because the doubts are varied and require contacting different experts; and should not be very disruptive to office work, since the contacts are occasional. However, this is well aligned with our observation that the field team is the one that pushes forward the geological mapping process. These arguments suggested using some type of instant text messaging mechanism.

We now briefly describe the redesigned geological mapping process afforded by these two major design decisions. Before going to the field, experts collect relevant data, including maps and documents related with the site where geographical mapping will take place. All this information is stored in the field book. This new functionality affords managing geo-referenced information with a centralized knowledge repository. While in the field, when doubts arise and a second opinion or comments are necessary, the field team may get in contact with the office team. Then, both field and office workers exchange comments on the subject at hand. The elements in the field book may be synchronized to keep the conversation in context. Our assumption is that, by sharing the field book, the experts increase their ability to make sense out of data. We also assume that the maps do not have to be remotely exchanged,[2] since they may be synchronized during the preliminary work done at the office.

To resolve problems, the office team may have to consult additional information in the IGM databases, or perhaps contact other experts. During these periods the field team may continue collecting data in the field. To get in touch again, one team may bring the other team back in conversation with an audible signaling mechanism.

The field team has now an easier task when moving back to the office. Because many problems and doubts may have been resolved, there is less time spent in the office consulting other experts. Compared with the traditional geographical mapping process, this new process, reduces the delays associated to having people coming and going to the field to analyze additional data; and affords parallel activities to be carried out in different places to accomplish the common objectives of both teams.

Addressing the observation made in episode one that knowledge should be geo-referenced, the instant messages exchanged between the field and office teams are preserved in the field book with associations to the geographical position of the field team, thus keeping the doubts, comments or opinions in their context.

4.5. Implementation

In the implemented prototype we tried to address the high mobility of field workers, preserving as much as possible the freedom to analyze the geology of the territory while using the hands for tasks such as using the hammer, compass, GPS, etc. The selected form factor was a laptop. Although the mobility criteria would suggest the use of a Personal Digital Assistant, the kind of field work addressed in this research required higher screen sizes.

The prototype was developed around two main artifacts: field book and map/transparent overlay. Concerning the map and transparent overlay, we substituted them with a GIS tool.

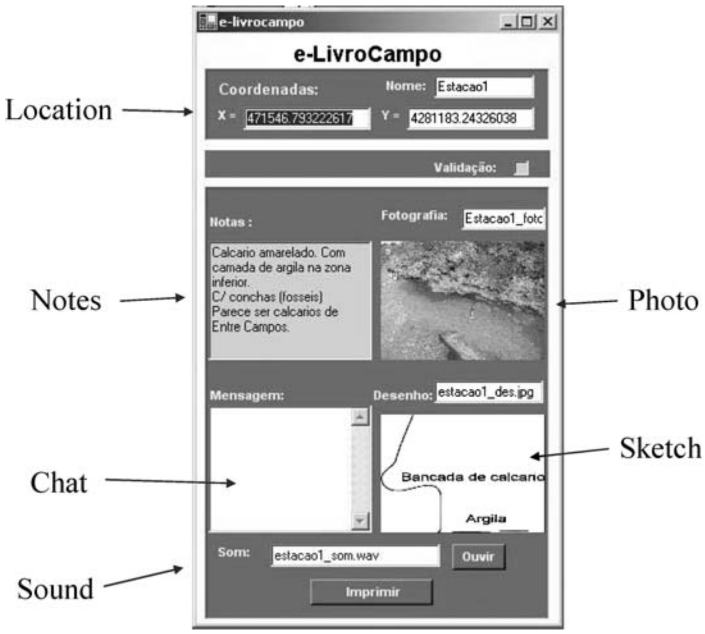

Figure 5. Digital version of the field book.

Our solution uses ArcPad® (ARCPAD) a mobile GIS tool belonging to the ArcGIS Mobile Software suite from ESRI® (ESRI). This tool allows manipulating maps using a laptop. ArcPad and ArcGIS were selected because they are commonly used by IGM.

Therefore, the major development efforts were applied to the field book. The field book has three major components: (1) a repository dedicated to preserve all information related with the geographical mapping process; (2) a user interface component dedicated to gather information into the repository; and (3) a user interface component allowing users to display, search and print geo-referenced data from the repository (see one screen dump in Figure 5). These three components were developed with Visual Basic .NET®, basically because it facilitates the integration with ArcPad. To support data capture and integration, the field book interfaces with a GPS device, digital camera, microphone and sound recorder. The types of data managed by the field book are: (1) geographical coordinates, taken directly from the GPS device; (2) notes, where geologists write doubts, descriptions and comments; (3) drawings of geological/topographical elements; (4) photographs; (5) sounds of the geological hammer striking rocks; and (5) text messages exchanged between teams and related with the specified geographical coordinates.

To support collaboration between the field and office teams, we developed a tool designated SAGISc. SAGISc uses MSN® Messenger to connect the field and office workers. We implemented an audio warning mechanism in SAGISc to bring the field and office teams together from situations where parallel work is being conducted and the device is unattended. The adoption of MSN Messenger was mostly because it is available in current workplaces at IGM, and affords the immediacy of contacts from field teams. We developed a mechanism to automatically export MSN messages into the field book and combine them with GPS information.

SAGISc also support synchronizing the field book elements between teams. The tool will attempt to synchronize whenever a team finds it necessary, but on explicit demand and per-object basis to avoid communications overload. Currently, SAGISc does not support synchronizing any ArcPad elements. Finally, we adopted a replicated architecture for SAGISc, with replicas of SAGISc running in the field and the office, connected through the General Packet Radio Service (GPRS) over the mobile telephone network.

4.6. Evaluation

The prototype evaluation was conducted in two successive steps. In the first step we carried out a pilot test, with users actually working in the field with the prototype. The test was done with experts from IGM, where the field team was composed by one geologist and the office team was composed by three experts in different areas in Geology. After this pilot test, we set up a demonstration aiming to explain the prototype to 30 specialists in geo-sciences from IGM and obtain additional comments about the prototype.

4.6.1. The pilot test

The pilot test was carried out in circumstances very close to reality, during which a field worker was sent to Oeiras (located approximately 15 Km West of Lisbon) with the goal to verify and discuss the geology of the area with the team that was in the IGM main office. The field worker was a geologist with low experience in this kind of work (geological mapping in the field), because her specialization area is Micropaleontology. The office team was composed by three specialists in geo-sciences (a geologist, hydro-geologist and geological engineer). Both teams were given the necessary hardware and software, and briefly instructed on the prototype usage.

The field worker carried the following equipment: a laptop with a GPRS card, GPS, compass, geologist’s hammer, microphone and digital camera. The software included in the system was: SAGISc, ArcPad, Olympus Camedia®, Notepad®, Freehand®, Sound Recorder® and MSN Messenger. See Figure 6 for details. The IGM team had the following equipment: PC connected to the Internet, SAGISc, ArcPad, MSN Messenger, scanner and telephone. See Figure 7 for details.

The participants in the pilot test were all individually interviewed about the prototype strengths and weaknesses. The obtained results indicate that the system increased sensemaking and collaborative capability. Related to sensemaking, the participants regarded very positively the expeditious way to locate points and insert information related with these points in the field book. Related with collaborative capability, the participants were extremely favorable to the component supporting the communication between field and office workers, effectively resolving problems occurring in the field and thus simplifying the whole geographical referencing process. The participants experienced a very positive utilization of SAGISc at the second located point where, through exchanged messages, the inexperienced field worker was able to identify the type of geology of the area.

Figure 6. Field worker using field book (laptop) hammer, compass and GPS.

Figure 7. The office team working around the field book at IGM.

A small problem arose with wireless communications, because one of the located points was on a cliff close to the shore and originated service losses. The participants also mentioned that the user validation phase and file exchange with MSN Messenger suffered from considerable communication delays. The reproduction of the sound of the hammer striking rocks did not resulted as expected, because of insufficient quality, and thus the IGM team could not remotely identify the rock formations.

We emphasize that the trial test was successfully accomplished by a person that was not proficient in that particular task and thus had many doubts. Collaboration support was crucial to success.

	Distribution of responses (Likert scale 1-very bad 5-very good)						
	N/A	**1**	**2**	**3**	**4**	**5**	**Average**
Experience							
With information technology		1	3	15	9	2	3,3
With field work		1	2	8	10	9	3,8
Usability							
ArcPad		1	2	12	11	4	3,5
SAGISc				3	18	9	4,2
Opinons about new work process							
Easier individual work	1		2	1	15	11	4,1
Easier IGM work	1		1	2	16	10	4,1
More opinions exchange		1			10	19	4,5
More observation/analysis capacity		1	1	3	17	8	4,0
More capacity to obtain 2nd opinions				2	13	15	4,4

Figure 8. Results from the questionnaire to the 30 IGM experts that participated in the demonstration session.

4.6.2. The demonstration session

We complemented the field trial with a demonstration session with a panel of 30 specialists in geo-sciences from IGM. The demonstration involved a detailed explanation of how ArcPad, digital field book and SAGISc were used to support field work, reproducing the pilot test and showing photographs, exchanged messages, the obtained outcomes and how both teams collaborated. After these detailed explanations the participants were requested to respond to a questionnaire about (see Figure 8):

- **Experience with information technology and field work** – We requested the participants to position themselves in terms of expertise with information technology and field work. The panel participants consider themselves as having median experience in both cases. This indicates that the evaluation was not biased by people having significant conceptions or preconceptions about the prototype functionality and use context.
- **Comparison between the ArcPad and SAGISc usability** – We requested the panel to compare the perceived usability of ArcPad and SAGISc. Both tools were considered easy to use, with a small advantage given to SAGISc. We interpret these results as supporting our assumption that the paper-less combination of SAGISc, field book and ArcPad may effectively substitute the field book and map/transparent overlay previously used.
- **Comparison between the old and new process** – We asked several questions to compare the old geographical mapping process with the new one: (a) Will SAGISc make your individual work easier? (b) Will make the work developed by IGM easier? (c) Will make the exchange of opinion easier? (d) Is it quicker to get a second opinion using SAGISc? (e) Is there and increase in observation/problem analysis abilities using SAGISc? Overall, the panel classified the new process as good or very good, rating by order of importance that the process is very good for exchanging opinions, it will be easier to obtain a second opinion, fieldwork will be facilitated, and the observation/analysis capability will be increased. We also noted that only a very small fraction of the panel participants regarded the new process as negative in fieldwork.

Combining the results obtained from this demonstration session with the results from the pilot test, we observe that the prototype received good acceptance and was considered useful for geological mapping. Analyzing in more detail what aspects of the prototype contribute more to facilitate geological mapping, both the panelists and field testers expressed their preferences for the support to data exchange, increased capability of observation and analysis and increased capability to obtain a second opinion. We interpret these results as endorsing our argument that the proposed prototype increases sensemaking and collaborative capacity.

As shown in the field test, the proposed approach can effectively resolve questions and doubts while on the field. The participants also expressed the opinion that the approach may facilitate the work at IGM. We interpret these results as supporting our view that the whole geological mapping process can be reduced by this approach.

5. Framework Analysis and Implications for Design

In this section we analyze the proposed contextual framework, based on the results obtained with the case study and discuss its applicability to other projects involving geographically referenced work in the field. One important advantage of using an exploratory contextual framework is having some preliminary guidelines about what field data has more potential to influence design. Our contextual framework identifies artifacts as the most important area of concern, not only because most of synchronous groupware systems rely on shared artifacts to support communication, coordination and collaboration but, most importantly, because of the collaborative capability and sensemaking issues, which are closely tied to artifacts.

The IGM case study illustrated a situation where the geological mapping process was facilitated by the increased field book collaborative capability, since users were able to immediately resolve problems. In relation to sensemaking, the case study also illustrated an interesting situation were workers had hidden difficulties with their sensemaking activities that were resolved by the proposed design solution: previously, when coming from the field to the office, collaboration was difficult because the field book could not recreate the adequate context of the work done in the field. The supplied design solution preserves doubts, comments and communications between experts in the appropriate geographical context, thus facilitating the completion of the jigsaw that characterizes geological mapping. In summary, we can say that the exploratory contextual framework pointed directly towards the main areas of concern that informed our design solution for the IGM case. The evaluation confirmed the relevance of the adopted design solutions.

Now, the question that arises is to understand if our exploratory framework can be applied to other cases. Another important question is to understand if the framework is not one of those "grand theories of everything" (Briggs 2004) that yield no insight to designers. We emphasize that, because of the exploratory nature of this research, the issue is obviously open and requires application to other cases. But we also accentuate that this research also gathered some evidence in favor of the framework:

- The case study showed that geo-collaborative system requirements can be articulated through the framework to inform the groupware design.
- The case study also showed that the research questions implied by the conceptual framework worked well in conjunction with the contextual design approach to develop a useful prototype.

Both sensemaking and collaborative capability have been studied in other contexts. For instance, collaborative capability has been studied in the context of the intellectual bandwidth theory with positive results (Nunamaker et al. 2002). The exploratory framework proposed in this paper is building upon these results, applied to the particular context of geo-collaboration. The approach requires the designer, in the initial design stages, to identify meaningful ways to articulate places, users, tasks, artifacts and geo-referenced knowledge. The technical issues pertaining to collaborative technology (communication, information gathering, coordination, access mechanisms (Pinelle et al. 2003)) are transferred to later development stages.

The proposed exploratory framework is used in combination with a design process. The design process itself is fundamentally based on the contextual design approach, which is one of the most popular design approaches addressing collaborative contexts and ethnography techniques, as referenced by the literature (e.g. (Spinuzzi 2000)). Therefore, our approach is also building upon these results. However, we would like to emphasize that although the contextual design approach describes how to elicit data from users and design from that data, it does not address the issue of what data is most relevant to start with the elicitation process. Our research goals, being focused on geo-collaboration, afford us to propose the articulated list of research questions implied by the framework and therefore expand the contextual design approach.

We note that the conceptual framework must be considered a starting point for design that is naturally liable to continuous improvements in focus and detail during the design process. Throughout the development of the case study discussed in this paper we continuously evolved the framework towards more concrete elements related with the tasks, artifacts and geo-referenced knowledge elements. For instance, the later versions of the framework characterize and articulate with detail the data types and the search and display capabilities that make up the geo-referenced knowledge component.

Finally, we conclude this section with a list of observations that may help practitioners develop better geo-collaborative systems:

- In this work context, all activities are geographically referenced. The collaboration support should preserve such geographical references even for informal communication between users. This situation challenges current groupware tools which do not support GIS integration.
- The information obtained in the field is varied, including text, pictures and sound. For instance, we found an interesting situation where the users had to exchange sound to identify a rock formation (even though the quality of the recorded sound disallowed proper identification). This situation challenges current GIS tools which do not support the integration of such diverse data.

- One of the most well regarded prototype features allows users to maintain the work context, including places images, comments etc. The prototype brings such data in a meaningful way and facilitates evoking and reconstructing relevant events that occurred long time ago in the field.
- The combination of field and office work in geo-collaboration is difficult because, on the one hand, field workers urge to resolve problems immediately as their appear, while, on the other hand, office workers may have their own agendas. In our case we observed that office workers were willing to participate because they experienced in the past the disadvantages of having to go to the field to confirm data, sometimes in uncomfortable places.
- Also related with the previous issue, we developed an audio signaling mechanism that facilitated bringing office and field workers together, thus allowing office workers to proceed with their independent tasks when necessary.

6. Conclusions

We propose a conceptual framework identifying several design issues that fundamentally set the stage for eliciting the requirements of geo-collaborative systems, with people working in different locations, gathering data in the field, where knowledge must be shared and geographical references must be preserved. The conceptual framework was combined with contextual design (Beyer and Holtzblatt, 1998), a user centered approach to systems design. The conceptual framework specifically contributes to the contextual design approach by delimiting the boundary of the data elicitation process and defining preliminary questions about the geo-collaborative work context.

The conceptual framework identifies five major elements in the geo-collaborative work context: places, teams, tasks, artifacts and geo-referenced knowledge. Besides these elements, and considering artifacts as the pivotal elements in geo-collaborative systems, we identified two major relations between the artifacts, tasks and geo-referenced knowledge: collaborative capability and sensemaking. Collaborative capability is a task-artifact relationship that emphasizes the need to increase the teams' decision making abilities through concerted efforts (Nunamaker et al. 2002), while sensemaking is an artifact-knowledge relationship that addresses the need to support mechanisms for jointly understanding data (Larsson 2003).

The suitability of the conceptual framework to drive groupware design was analyzed with a case study. The project goal was building a collaborative system for teams working in geological data gathering at IGM, a national agency responsible for mapping geological resources under the Portuguese jurisdiction. We explained in detail how the conceptual framework influenced the data gathering process. Afterwards, we described the work redesign and gathered requirements for developing the groupware prototype. The prototype is centered in the support to the two artifacts that emerged from the application of the conceptual framework: the field book, an artifact where the field worker gathers several types of data related to geological mapping; and the map/transparent overlay allowing users to localize data and append symbols to the map. The developed prototype allows sharing information in the field book and supports collaboration between remote and local teams, increasing sensemaking and collaborative capability. The prototype was evaluated in a field trial and demonstration session. According to the obtained results, the collaboration component is the most positive one, the reason being the possibility of decreasing the duration of geological data gathering.

Although the proposed conceptual framework was only evaluated to success with a case study, we argue that the case study revealed two important contributions to the design of geo-collaborative systems:

- The fundamental requirements of geo-collaborative systems can be articulated through the framework, focusing the designer on the human aspects of geo-collaboration rather than system functionality.
- The conceptual framework was well integrated with the contextual design approach, guiding the designer in the initial design stages, where research questions are necessary to elicit the work context.

Notes

1. Further details and validity tests can be found in (Qureshi et al. 2002; Qureshi and Briggs, 2003; Bach et al. 2004).
2. Which would impose significant requirements to any groupware implementation, considering the types and varieties of maps used by these experts and the types of wireless networks currently available.

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