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KEY INDICATORS FOR ASSESSING THE DESIGN OF GEOCOLLABORATIVE APPLICATIONS

PEDRO ANTUNES

Faculty of Sciences, University of Lisbon, Campo Grande,
Lisbon, 1749-016, Portugal
paa@di.fc.ul.pt
http://www.di.fc.ul.pt/~paa

GUSTAVO ZURITA

Economy and Business School, University of Chile, Diagonal Paraguay 257
Santiago, Chile
gzurita@ing.puc.cl

NELSON BALOIAN

Engineering School, University of Chile, Blanco Encalada 2120
Santiago, Chile
nbaloian@gmail.com

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A geocollaborative application integrates geographical information with collaboration support. Its implementation involves reasoning about the most adequate mix of technical features, human requirements and collaboration models. This paper proposes a framework for guiding and assessing the design of geocollaborative systems using a set of measurable indicators. We define five key indicators: awareness, mobility, proximity, collaborative visualization and geographic relationships. These key indicators were derived from an extensive review of the state of the art. The framework was validated in two case studies involving support to geologists working in the field and police agents evacuating crowded places. The case studies elucidate how the framework helps analyzing as-is and to-be collaborative scenarios, which constitute the design cycle posited by the design-science paradigm. This research is relevant to implementers in two ways: highlighting important qualities of geocollaboration systems and offering a structured mechanism to assess the design process.

Keywords: Geocollaboration, collaboration support, design assessment.

1. Introduction

For thousands of years mankind has been using maps to support various tasks related with geographical information. Nowadays, with the popularity of Geographical Positioning Systems (GPS), Geographical Information Systems (GIS) and various types of portable computing devices, combined with advances made in human-computer interaction, we observe a greater than ever reliance on maps. People are manipulating geographical landmarks to work, play, travel, drive, buy and carry out many other common activities.[1] Massive graphical multiplayer online games like Star Wars Galaxies and The Sims Online are taking advantage of the combination of maps with information systems and human-computer interaction.[2] Widely used tools like Google Maps, Open Street Maps and Yahoo! Maps are being combined with social features to support group activities.[3] Commercial services like City Sourced and See-Click-Fix also exploit the synergies between geographical information systems and online presence to offer innovative community services.

The concept of geocollaboration concerns the combination of geographical information with collaboration support.[4,5] This particular combination is being widely researched and has already lead to many innovative applications. Examples include gathering and managing geospatial data in the field,[6-8] making geospatial decisions in crisis situations,[9,10] emergency response,[11,12] mobile knowledge creation and management,[13,14] and strategy making.[15,16]

We regard the design of geocollaborative systems as a creative, exploratory and research-oriented activity. Adopting the design-science[17] paradigm, this requires focusing on a build-evaluation loop, where building serves to establish relevance and evaluation provides feedback information and a better understanding of the problem. Considering this scenario, our main research goal is developing a framework for evaluating design ideas and solutions. We hypothesize that the framework: (1) helps establishing the essential design qualities, mixing technical considerations over information management with human requirements related with collaboration support; (2) maintains control over the build-evaluation loop posited by the design-science paradigm, using a set of measurable key indicators; and (3) facilitates the assessment and benchmarking of geocollaborative systems.

The preoccupation with building evaluation frameworks is quite old. It may indeed be traced back to the Roman architect Vitruvius who, while working for the emperor Caesar Augustus, developed a framework with building qualities.[18] In what may be viewed as the ultimate synthesis,[19] Vitruvius characterized architecture as the practical and theoretical consideration for three qualities: commodity, firmness, and delight. A very similar approach has been adopted in the software field, where architectural styles and software design patterns exploit design knowledge and guide implementers in constructing systems.[20]

In this paper we propose a set of quality key indicators (KI) that codify challenges and problems associated with the development of geocollaboration systems. As with software patterns, they are derived from informal knowledge described in the related literature.

The paper is organized as follows. We review the related literature in Section 2, identifying and structuring the main geocollaboration concepts. Based on that review, in Section 3 we synthesize a set of KI and propose a framework for assessing the design of geocollaborative systems using the KI. Section 4 presents two case studies where the framework was applied to the development of two applications, one concerning geologists working in the field and the other supporting the police evacuating crowded places. Section 5 discusses the obtained research results and its implications to implementers. Our conclusions are presented in Section 6.

2. Major Concepts Related with Geocollaboration

The notion of place has for long been considered fundamental to understand collaboration support. The early conceptualizations of place assume it is inherently associated with physical proximity: "Computer keyboards, current documents, common reference materials and favorite pieces of music might immediately surround us in an office, while other materials are kept further away."[21] In this case, the "office" is a place characterized by the surrounding affordances: "place is the understood reality."[21]

The time/place map, originally proposed by Johansen et al[22] and still widely used in the related literature,[23] highlights the opportunities offered by collaboration technology in shaping the notion of place. It defines four work arrangement derived from time distinctions (same-time/different-time) and physical space distinctions (same-place/different-place). It also suggests a fifth work arrangement where collaboration may occur independently of time/place distinctions (any-time/any-place).

This map leads some researchers to observe that space is not only characterized by physical proximity but also by virtual proximity.[21,24,25] The main argument is that collaboration technology has affordances that allow teams to develop virtual places where the understood reality extends beyond the physical limits.

The subsequent expansion of the place dimension in three categories, considering co-located, virtual co-located and remote places addresses these affordances.[26-28] Co-located places depend on face-to-face interaction. Virtual co-located places use audio and video communication channels to give the impression of being in the same place.[29,30] And remote places depend on data sharing to afford some mitigated sense of proximity. Studies of media richness[31] and media naturalness[32] show that co-located and virtual places degrade important communication features such as nonverbal cues, rapid feedback and arousal. In this line of reasoning, proximity is more dependent on the medium than the physical location of the team.

Places exist in spaces.[24,25] Actually, spaces have been defined as containers of places.[33] In our literature review we identified five different spaces, each one addressing one particular type of relationship between place and space.

Geographical space: The first type we identify is the geographical space, which fundamentally constructs a representation model based on two main concepts:[24,33] location, which serves to position an object in space; and distance, which serves to compute the nearness of two objects belonging to the same space. Dix et al[33] also add the notion of orientation, which serves to enrich the computation of the relative awareness of other objects in the same space.

Physical space: Another space we consider is the physical space, which is associated with the constraints enforced by the physical world. One main concern introduced by physical spaces is mobility. Mobility is important because any interaction with a space is embodied:[34] action is always a physical manifestation in the world, even if the world is not strictly a physical world. We find in the literature three types of mobility: wandering, visiting and traveling.[35] In the same line of reasoning, although focusing more on technological support, Dix et al[33] proposed the following levels of mobility: fixed, mobile, autonomous, free, embedded and pervasive. Each one of these levels imposes different constraints to the technological support, especially regarding communication and information processing.[36]

Hazas et al[37] introduce location awareness as a means to determine physical location using sensing technology such as GPS and RFID. Hazas et al[37] also make the distinction between physical and semantic locations, the later abstracting the actual physical locations using a hierarchy of concepts like rooms, floors and buildings.

Virtual space: Rodden[38] developed the notion of virtual space as a collection of computer-supported and interactive spaces. Many collaborative applications implement different types of virtual space having varied functionality, like virtual meeting rooms, media spaces, multi-user recreational environments and collaborative virtual environments.[39] Virtual spaces may also adopt different navigational structures such as clusters, stacks, lists, tables and rooms.[40]

Collaborative visualization is a fundamental attribute of virtual spaces, as it serves to navigate the virtual space while sharing the interactive experience with the group members.[13,41] Collaborative visualization may extend from simple data exchange towards more complex shared control and dynamic interaction capabilities.[23] Data exchanges are necessary to maintain some degree of shared involvement. Shared control complements data exchange with coordination mechanisms governing the group's interactions with the virtual space. And dynamic interactions afford finer-grainer control over coordination and higher levels of interdependence when interacting with the virtual space.

Rodden[38] emphasized the importance of supporting awareness about the group interactions with the virtual space. He developed a conceptual model of context awareness in virtual spaces using the notions of focus and nimbus. Focus and nimbus are subspaces that, respectively, map the attention and presence of elements in spaces. Related with context awareness, we also find the distinction between private and public spaces, the former pertaining to things and actions belonging to one single individual and the later shared among a group.[13,42]

Social space: Dourish[25] and Brewer and Dourish[43] proposed social spaces as necessary to understand broader issues related with spaces and social practices. In this context, social spaces combine geographical, physical and virtual affordances with social interaction, cultural meaning, experience and knowledge. Dourish[34] also proposed the notion of embodiment to account for the embedded relationships between social and the other spaces. These relationships seem quite common in our everyday experience. Dourish[34] exemplifies with metaphorical expressions like "his position is indefensible," revealing how embedded spatial concepts are in our social contexts.

Workspace: And we should finally analyze the workspace. According to Snowdon et al,[39] a place has inherent a set of activities that occur there and therefore a workspace may be defined as a container of places with ongoing activities. We find in the literature innumerous examples of workspaces, ranging from group editors[44] to hypermedia systems[40] and Spatial Decision Support Systems (SDSS).[23,45,46]

Liechti[47] emphasizes the group's need to perceive what is going on in the workspace. He defined peripheral awareness as understanding the activities being carried out by others nearby one's place. Gutwin and Greenberg[48] expanded this view to account for the whole space, defining workspace awareness as the understanding of another person interactions in a shared workspace using a basic set of questions: who, what, where, when, and how.

Endsley[49,50] expanded the notion of workspace awareness towards what is known as situation awareness: understanding what is going on in the working environment with the purpose to perform tasks effectively. Endsley[49,50] defined three levels of situation awareness: perception of elements in the current situation, comprehension of current situation and projection of future status. Situation awareness is crucial to the development of Emergency Response Systems.[11]

In Table 1 we outline the reviewed geocollaboration concepts. They are organized according with the categories and associated conceptual distinctions and attributes outlined above. The conceptual distinctions highlight what differentiates places and spaces, including the five different facets of space that were bring forth. Attributes provide further details about the conceptual distinctions. Overall, we elicited 6 categories, 9 conceptual distinctions and 38 different attributes of geocollaboration.

This table shows the complementarities brought by the several notions of space found in the related literature. It also shows that one fundamental concern with geocollaboration is awareness, which manifests itself in multiple ways, including location, context, social, workspace and situation awareness.

Table 1. Major concepts related with geocollaboration.

Categories	**Distinctions**	**Attributes**
Place (the understood reality)	Proximity	Same-place, different-place, any-place Co-located, virtually co-located, remote
Geographical Space (the representation model)	Geographical relationships	Location Distance Orientation
Physical space (constraints imposed by	Mobility	Wandering, visiting, traveling Fixed, mobile, autonomous, free, embedded, pervasive
	Location awareness	Physical location, semantic location

physical reality)		
Virtual space (information structure)	Context awareness	Focus, nimbus Private, public
	Collaborative visualization	Data exchange, shared control, dynamic interaction
Social space (social practice)	Social awareness	geographical, physical, and virtual, social interaction, cultural meaning, experience, knowledge, embodiment
Workspace (container of places with ongoing activities)	Workspace awareness Situation awareness	Who, what, where, when, how Perception, comprehension, projection

3. Key Indicators for Geocollaboration Design

One common design procedure in software product development is to differentiate the as-is and to-be stages.[51,52] The former is related with requirements definition and analyzing the existing situation, while the later concerns conceptualizing and specifying the future implementation. We find this approach in many organizational software developments like business process management[53] and enterprise resource planning.[54]

A property of the to-be stage is being open, since a multitude of choices may be taken based on different views about the existing situation, the identified alternatives, and also different criteria regarding what should be implemented.[55] This raises the problem of evaluating how better a to-be design may be when compared with the as-is situation and the alternative to-be options.

The problem of measuring design is not trivial and consists of both objective and subjective Key Indicators (KI).[56-58] Some KI may be objectively measured. For instance, researchers have developed objective measures for software reusability and flexibility.[59] However, other KI require subjective appreciation. For instance, Simon[55] refers to “style” as a subjective criteria. Another example from the information systems domain concerns the users’ opinions about quality and reputation of data available in databases.[60] Furthermore, KI may be useful beyond the mere objective to measure design performance. For instance, they can assist capturing users’ perceptions and thinking about design quality during the product development.[56]

The Capability Maturity Model (CMM)[61] suggests that proper KI should consistently identify goals, procedures, measurement practices, and verification activities. Berenguer et al[62] propose a method to define KI based on CMM and using the following structure:

1. Define objective
2. Identify the questions that the designer is trying to answer
3. Characterize the perspective or viewpoint
4. List the measures required to construct the indicator
5. Describe the algorithm necessary to construct the indicator

6. Provide information on how to interpret the indicator

In the following, we describe a set of KI for geocollaboration design using this structure. The rationale behind the KI choices and the links to the major concepts related with geocollaboration are given in the perspective/viewpoint elements.

Awareness (AW)

Objective: Evaluate the capacity of collaboration technology to express what is going on in the collaborative setting.

Perspective/viewpoint: The importance of AW was very clear in the review done in Section 2, which makes it a patent candidate for KI. AW concerns five of the nine conceptual distinctions we identified in Table 1. Users construct awareness about their physical, virtual, social and work spaces based on signals, interpretations, memory, attention and perception. We assume that increasing the diversity of conveyed signals contributes to a better perception of the various elements belonging to the collaborative setting and thus leads to better collaboration.

Questions that the designer is trying to answer: Is the system conveying rich information about the collaborative setting? Are the various known types of awareness supported?

Measures required to construct the indicator: Based on the taxonomy presented in Table 1, we identify five different types of awareness. We classify AW in a numeric scale counting the following design attributes:

> *location* (Location awareness gives indications about the users' physical and/or semantic locations)
>
> *context* (Context awareness locates users in the information space and shows them how the space is structured, populated by other users and artifacts, and also the type of information access)
>
> *workspace* (Workspace awareness shows the structure of activities and indicates who, what, where when and how they are carried out)
>
> *social* (geographical, physical, and virtual, social interaction, cultural meaning, experience, knowledge, embodiment)
>
> *situation* (Situation awareness provides cues necessary to perceive, understand and project the future status of ongoing events, focusing especially on individual, coordinated and collaborative activities)

Algorithm necessary to construct the indicator: The domain of AW is defined

> *dom AW = Location x Context x Workspace x Social x Situation* where each set in the product indicates the presence or not of the attribute
>
> Each design j is represented by a 5-tuple
>
> $< a_1 , a_2 , a_3 , a_4 , a_5 >$ where $a_i = 0/1$
>
> AW is measured for each design j
>
> $AW\ (design\ j) = \#\ \{a_i = 1,\ \ 1 \leq i \leq 5\}$

How to interpret the indicator: Currently, this indicator does not provide a qualitative assessment of individual awareness elements, e.g., how good is the support to location or context awareness. It is essentially focused on the diversity of the signals provided to users. Another aspect that is not been considered is the different degrees of technical complexity imposed by the different types of awareness. For instance, location awareness may be more easily implemented than situation awareness, as the former can be constructed from visualizing the elements in the workspace, while the later may require implementing a causal model. Thus, for implementers, this indicator is a reminder that awareness builds upon diverse elements associated with the collaborative setting.

Mobility (MB)

Objective: Assess the level of mobility supported by the collaboration technology.

Questions that the designer is trying to answer: Can users move around while using the system? The technology has to be carried out by the users?

Perspective/viewpoint: MB is a major distinction of physical spaces, along with location awareness. It supports information access while on the move, offers flexibility to carry out tasks independently of physical constraints, but also allows coordinating tasks that depend on the physical context. Support to mobile users is gaining momentum because of the recent developments in mobile networks and mobile devices, which are leading to more sophisticated applications.[63] Our assumption is that the increased sophistication of the applications is directly related with the increased level of MB support.

Measures required to construct the indicator: Based on the mobility taxonomy proposed by Dix et al,[33] we may classify MB in a ordinal scale considering the following design attributes:

fixed (Artifacts are fixed in space)

carried (Artifacts may be carried by users throughout the space)

autonomous (Artifacts move autonomously on the space)

pervasive (Artifacts pervade all over the space)

Algorithm necessary to construct the indicator: The domain of MB is defined

dom MB = {fixed, carried, autonomous, pervasive} where *fixed* $\prec$ *carried* $\prec$ *autonomous* $\prec$ *pervasive*

MB is measured for each design j

MB (design j) $\in$ *dom MB*

How to interpret the indicator: It provides a qualitative assessment of the possibilities brought by mobile and pervasive technology, motivating implementers to explore collaborative situations characterized by constant interaction with the group and the environment.

Proximity (PR)
Objective: Assess the different work places supported by the collaboration technology.
Questions that the designer is trying to answer: Are the users restricted to collaborate in a single place? Can they work in different places? Can they switch work places according with their needs and preferences?
Perspective/viewpoint: Although collaboration should be supported anytime and anywhere, that in practice is quite difficult to achieve, since the technology often restricts the medium richness, which defines the notion of place (see Table 1). We assume that increasing proximity will help users become less dependent on technological constraints and more flexible to work on the most adequate places to their needs and preferences.
Measures required to construct the indicator: Based on the taxonomy proposed by Rodden and Blair,[27] we classify the measure of PR in a ordinal scale considering the following design attributes:

> *single place* (Design supports one single place, either co-located or remote)
>
> *dual place* (Design supports co-located and remote places, but the users are subject to the corresponding architectural restrictions)
>
> *virtual place* (Design supports users located at different and same places, acting as virtually in the same place)

Algorithm necessary to construct the indicator: The domain of PR is defined

> *dom PR = {single place, dual place, virtual place}* where *single place* $\prec$ *dual place* $\prec$ *virtual place*
>
> PR is measured for each design j
>
> *PR (design j)* $\in$ *dom PR*

How to interpret the indicator: As with AW, this indicator currently exhibits some limitations. For instance, we are not accounting for the diversity of communication channels that may be used by the group, neither the information richness supported by each channel. Nevertheless, this indicator reminds implementers to focus on the capacity to maintain collaboration independently of space and time, thus giving users' more control over their activities.

Collaborative Visualization (CV)
Objective: Assess the capacity of collaboration technology to support data visualization and interaction.
Questions that the designer is trying to answer: The system visually manages shared data objects? What degree of interaction control is supported?
Perspective/viewpoint: We regard CV as the basic driver of virtual spaces (in conjunction with context awareness), allowing users to organize their activities through shared data objects. This indicator highlights our assumption that increasing visualization richness

leads towards increasing collaboration levels, such as the ones supported by interactive simulation environments.
Measures required to construct the indicator: Based on the taxonomy proposed by MacEachren and Brewer,[23] we classify CV in a ordinal scale covering the following design attributes:

none (Design does not support any collaborative visualization technique)

data exchange (Design only supports data exchange)

shared control (Design combines data exchange with shared control over existing artifacts, thus allowing to coordinate activities)

dynamic interaction (Design supports dynamic interaction with existing artifacts)

Algorithm necessary to construct the indicator: The domain of CV is defined

dom CV = {none, data exchange, shared control, dynamic interaction} where *none* $\prec$ *data exchange* $\prec$ *shared control* $\prec$ *dynamic interaction*

CV is measured for each design j

CV (design j) $\in$ *dom CV*

How to interpret the indicator: CV contributes to analyze how groups may exploit the technology to construct, visualize and interact with shared data. Thus unlike AW, MB and PR, which regard the technology as a medium with various capacities, CV considers technology as a tool extending the users' capacities. The key issue for implementers to consider is developing more sophisticated visualization and interaction features along with collaboration support.

Geographical Relationships (GR)
Objective: Assess the support to geographically related collaborative activities.
Questions that the designer is trying to answer: The technology shows where the users are located? Can the users perceive the distances between them? Can the users recognize the others' focus of attention?
Perspective/viewpoint: Geocollaboration necessarily requires perceiving the spatial relationships between people and objects present in workspaces, which may be supported with various levels of detail. We assume that increasing the diversity of geographical relationships contributes to a better perception of the work structure, which may contribute to better collaboration.
Measures required to construct the indicator: The increasing capacity to manage geographical relations in a space may be classified in a numeric scale counting the following design attributes:

location (Design supports locating users in the space)

distance (Design supports distance relationships) *orientation* (Design supports orientation)

Algorithm necessary to construct the indicator: The domain of GR is defined

dom GR = Location x Distance x Orientation where each set in the product indicates the presence or not of the attribute

Each design j is represented by a 3-tuple

$< a_1 , a_2 , a_3 >$ where $a_i = 0/1$

GR is measured for each design j

$GR\ (design\ j) = \#\ \{a_i = 1,\ \ 1 \leq i \leq 3\}$

How to interpret the indicator: Although conceptually distinct, in practice GR is related with MB and CV, in the sense that geographical relationships may be established in both virtual and physical spaces, or even across these spaces. Thus the challenge for implementers is twofold: in the one hand, provide rich contextual information about the geography of the collaborative setting; and in the other hand, link virtual and physical spaces in a meaningful way.

3.1. *Additional notes*

We observe that two different procedures were adopted to measure design attributes: ordinal measurement and counting of attributes. In some cases the counting of attributes is necessary because there is no obvious way to order the design elements. Consider for instance the AW indicator. Although we could define an ordinal scale ranging from location to awareness, workspace and situation awareness, it would be debatable how to position the social attribute. Therefore we consider the best approach in this case is to define a measure based on countable design attributes.

Furthermore, concerning the counting of attributes, we evaluate them using a 0/1 scale, denoting if a certain feature is present or not in a particular design. We neither evaluate the quality of that attribute nor the effort necessary to implement it. And we also do not consider the priority given to the attribute. A multiple criteria approach could be experimented in the future to overcome these limitations.[64]

We finally note that the selected KI cover all six categories defined in Section 2. Of the discussed 38 attributes, we are considering 18. Of course we could have developed a more extensive coverage. However, the adopted strategy consisted in covering all main categories using a minimum set with highly representative attributes, thus simplifying the assessment process.

4. Using the KI

We will now describe two design cases using the framework described in the previous section. The cases concern the redesign of a geological inventory process and the design of an application supporting police work while evacuating crowded places.

4.1. *Redesigning a geological inventory process*

This case involved work redesign in a public agency responsible for inventorying and valuing the Portuguese geological resources. The core activities of this agency include studying and mapping natural resources, developing risk maps, and producing geographical information systems. The case study was specifically centered on the geological inventory of the Portuguese territory.

The design process was organized according with the as-is and to-be steps. The first step inquired about the current geological inventory procedure. The preliminary data was collected through interviews with several experts from the agency. During the as-is step we identified two main workplaces: the office and the field. In general, the geological inventory requires multiple visits to the field to obtain various types of data, intertwined with consolidation activities done in the office. The visits to the field tend to be done by one person, while the office activities combine individual and collaborative work.

The inventory activities are organized around two different spaces (office and field) and two different places (visit and consolidation) having one-to-one relationships. Indeed, the inventory process seemed highly dependent on the relationship between place and space: many activities, such as determining the land structure, are done in the physical space, since the experts often need to move around to analyze physical evidence and determine the exact land structure. But these activities are also highly dependent on the notion of place, especially in what regards confronting the opinions from experts in different fields such as paleontology, petrology or sedimentology, which are done when consolidating work in the office.

After the preliminary interviews, we decided to obtain additional insights by observing and inquiring experts working in the field. We especially analyzed the artifacts used by these experts. Work in the field evolves around two artifacts: the field book and the combination of a map with a transparent overlay. The map/overlay allows representing the inventory data, while the field book serves to annotate supplementary information, including doubts and concerns that often occur during fieldwork.

After the two data elicitation phases we had the necessary elements to measure the KI associated with the as-is situation. Starting with AW, we observed the inventory process was grounded on location awareness: the field book, map and transparent overlay provide all necessary cues about the physical location. The other awareness elements were however more problematic:

- Whenever doubts occur, workers have to switch places, either because they lack workspace context (e.g., to triangulate with different physical evidence) or social context (to triangulate with different experts);
- We observed it was often difficult to use the book outside the field, because it would loose context. While consolidating in the office, workers often need to reconstitute the whole visit to put back in context the data recorded in the field book;
- Information was also scattered between the field book and map/overlay, which were difficult to co-relate.

Regarding MB, we observed that both the office and field spaces only support experts moving between spaces and carrying artifacts with them. Considering PR, we observed that the participants often switch between co-located (office work) and remote (fieldwork) places, but no technological support is considered for working virtually in the same place. On the CV subject, we observed that the inventory process does not support data exchange, virtual control or dynamic interaction, since the field book and overlay are inherently personal and loose value when the teams work in the office. The GR information is restricted to GPS data indicating the "stations," i.e. locations where field workers collected data. The measured KI are shown in Figure 1.

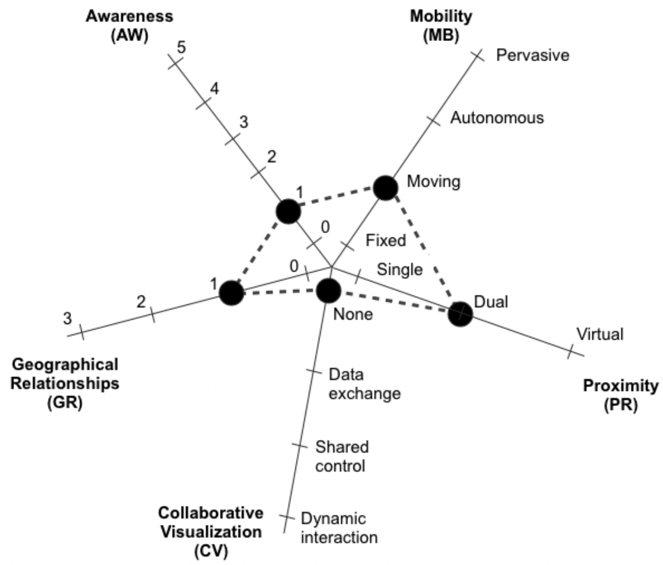


Figure 1. KI of the as-is situation (case 1).

We then proceed to the to-be step. In this step we analyzed the existing work situation with the purpose to find opportunities for innovation and work redesign. We identified three major opportunities:

- We may increase the value of the field book by making it a shared artifact;
- We may integrate the field book with the map/overlay, aiming to increase context and workspace awareness;
- And we may also integrate the visit and consolidation places, bringing all relevant stakeholders together to resolve problems as they appear in the field and in the office, aiming to reduce the time spent switching activities.

These design opportunities lead us to develop a prototype running on tablet and common PCs, and integrating the field book and map/overlay (see Figure 2). The prototype also merges the visit and consolidation activities into one single virtual place. This allowed the field workers, using tablet PCs, to get in contact with the office workers and immediately exchange comments, problems and doubts.

The prototype supports data synchronization over the GSM network, shared control and dynamic interaction. It also integrates the GPS with the map/overlay and instant text messaging. The exchanged instant text messages are preserved in the field book with automatic links to the geographical position of the field workers, thus keeping the doubts, comments and opinions in their proper context. Because many doubts are resolved in the field, there is also less chance to swing back and forth between the office and the field.

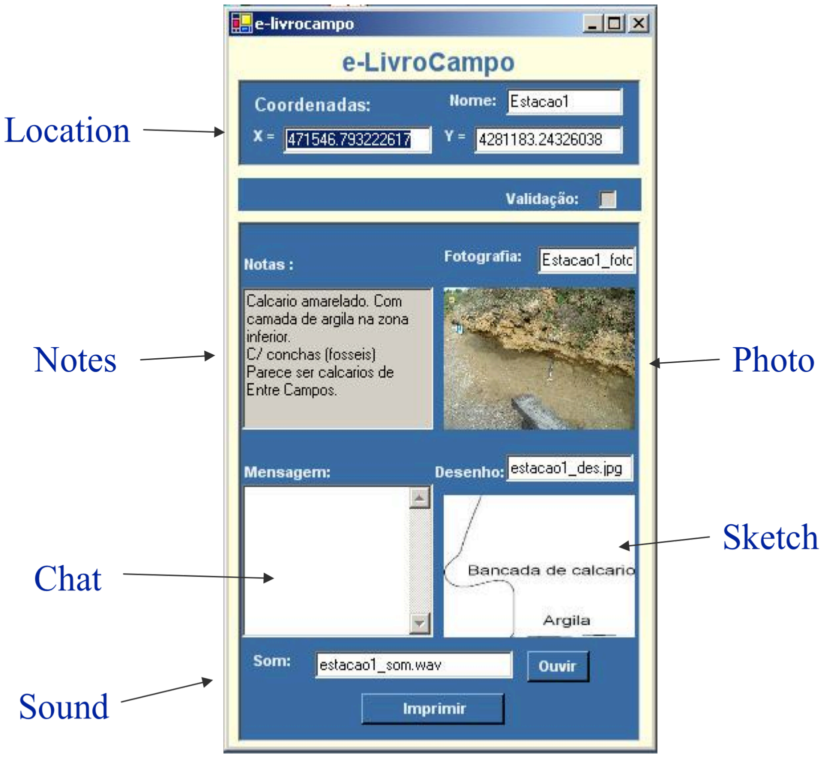


Figure 2. Developed prototype (case 1).

The measured KI of the to-be situation are shown in Figure 3. These measures show that three KI improved considerably. AW now comprises location, context and workspace awareness, since the prototype maintains geographical inventory data in context with the users' activities, exchanged instant text messages and the physical locations where the activities are carried out. MB still considers a mobile field book carried by the users indistinctly in the field and in the office. PR indicates that users now operate in a virtual co-located place where the activities may be carried out simultaneously in the office and in the field. CV indicates the users dynamically interact with the prototype to introduce, analyze and modify geological inventory data. And GR has not improved with the redesign.

The prototype was evaluated in field tests and contextual interviews with several experts from the agency. The obtained results indicate that the prototype improved the inventory process. In particular, the participants regarded very positively the expeditious way to locate geological elements and associate them in the field book (which justify the improved CV and AW). The participants were also extremely favorable to the synchronous communication support between field and office workers, effectively resolving problems occurring in the field and thus simplifying the whole inventory process (which justify the improved PR). More details about this case study may be found elsewhere.[7]

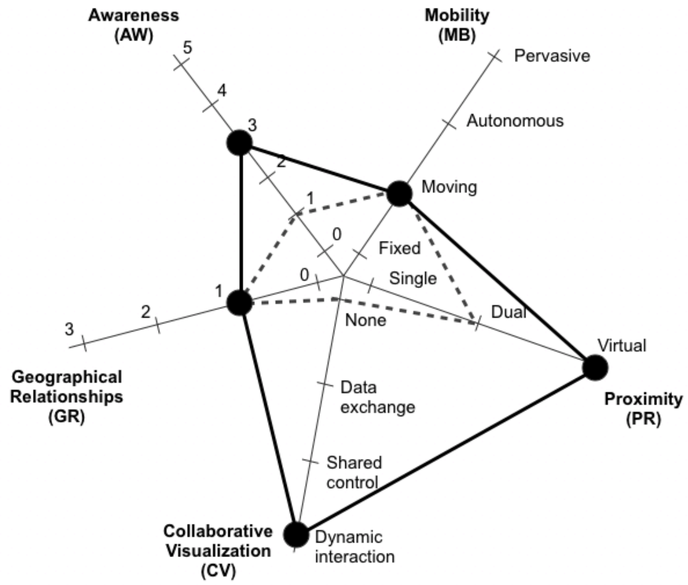


Figure 3. KI of the to-be situation (case 1).

4.2. *Supporting the evacuation of crowded places*

This case concerns supporting the police evacuating people from a stadium or any other facility with capacity for hosting thousands of people. The major problems to consider are finding adequate evacuation routes, spreading out people in congested places such as bus/metro stations and parking places, and dealing with high-density and fluid crowds. These are frequent problems faced by the police in Santiago de Chile, where sports fields with capacity for 80.000 people were built in surroundings close to the city limits and are now bordered by busy streets and dense inhabited city quarters. In these events, the police will place agents in strategic places to patrol people coming out from the stadium, showing them the planned evacuation routes.

Normally, each agent uses the radio device to maintain awareness, exchanging voice messages with the central police station and colleagues. The agents in the central station maintain a picture of the whole situation based on scattered information verbally provided by the agents. The central station may give commands to the agents in the field, managing any exceptional situations that may occur.

This is a typical geocollaboration situation where location and collaboration are of critical importance. Analyzing the situation in more detail, we may identify two spaces: station and field. The field includes several strategic places such as the stadium gates, streets, parking places, bus and metro stations. The agents have to control crowds in these places, giving instructions to the mob. They must also report any events that may escalate the situation and require changes to predefined plans.

The main problems here are maintaining awareness of the situation, understanding the whole picture and anticipating events using the radio devices. The KI measured for the as-is situation are shown in Figure 4. Considering the limitations of the radio channels, AW is set the lowest value. The MB variable is set to moving, since the agents in the field carry on radio devices. Considering the technology is designed for remote operation, PR is set to single place. CV is restricted to data exchange, considering the transmission of voice messages. And finally GR is set to the lowest value, since the technology was not designed to support location, distance and orientation.

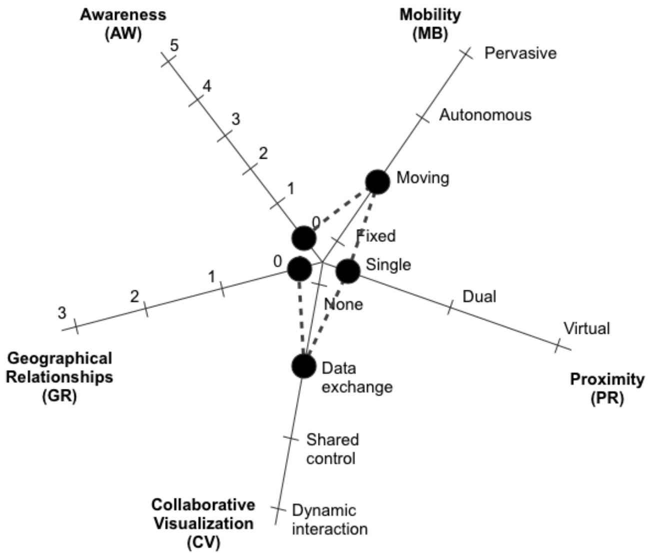
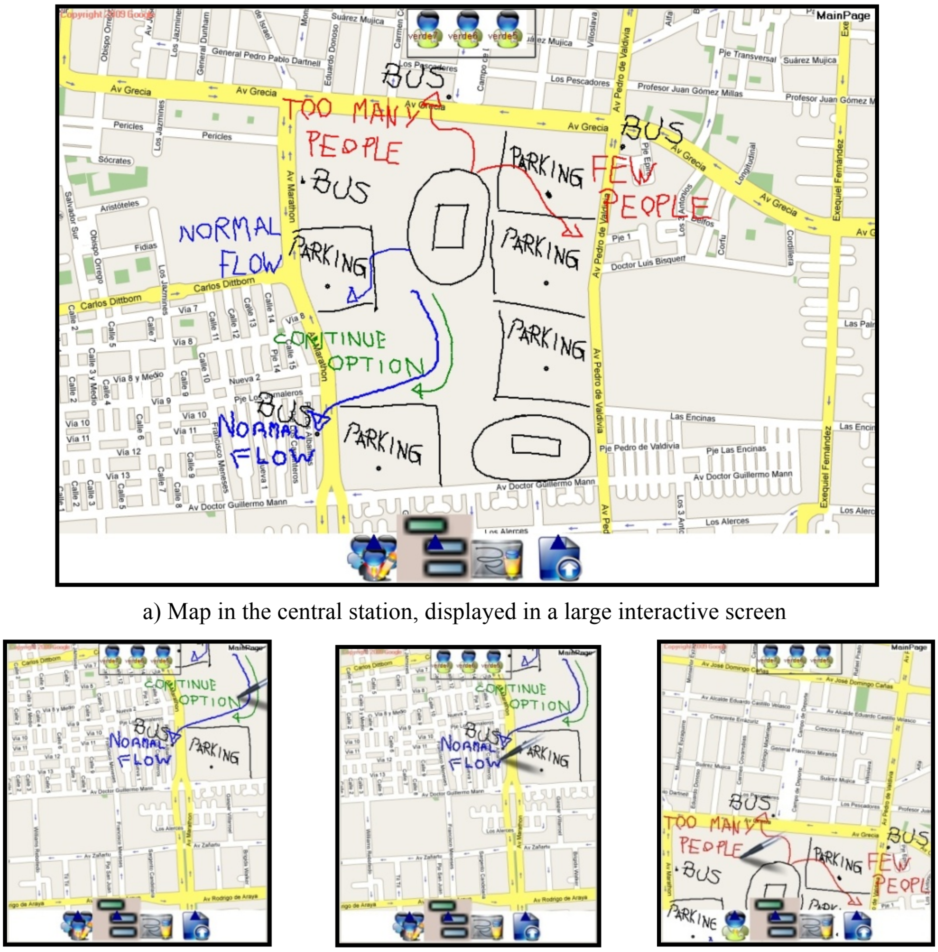


Figure 4. KI of the as-is situation (case 2).

Overall, we observe the as-is situation is characterized by low scores in most KI, clearly showing that the agents in the field and in the station must compensate the technological constraints with extensive use of the communication channel to maintain a picture of the situation.

In order to expand the area covered by the KI measurements, we developed a prototype supporting this activity (Figure 5). The prototype provides a shared map of the intervention space and can be annotated by the central police station based on the exchanged voice messages. Technically, the agents in the field may also annotate the shared map, but such type of usage is regarded less likely to occur, since it would imply the agents could lose the focus on their primary task, which would represent an unacceptable risk.



a) Map in the central station, displayed in a large interactive screen

b) Map in agent's PDA1 c) Map in agent's PDA2 d) Map in agent's PDA3

Fig. 5. Developed prototype (case 2).

The prototype allows agents in the police station to display the map on a big touch-sensitive screen showing the stadium and surrounding areas. The map is annotated using freehand writing and sketching. Each agent in the field has a Personal Digital Assistant (PDA) showing a portion of the map. The visible portion of the map is automatically adjusted to the agent's position thanks to an integrated GPS. All devices (the one running in the police station and those carried by field agents) are synchronized. All annotations are immediately distributed to all devices. In Figure 5 we show some screenshots of the map available in the police station (upper section) and three PDA carried by agents in the field (lower section).

The measured KI of the to-be situation are presented in Figure 6. These measures show that the to-be design offers improvements in three areas: awareness, proximity and collaborative visualization. The most significant improvement occurs with AW, because the adopted technology is now capable to maintain a shared view of the situation, facilitating understanding, interpretation and projection.

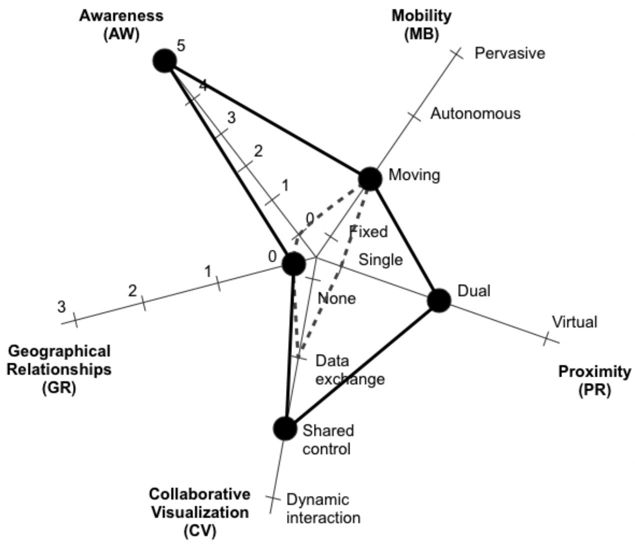


Figure 6 - KI of the to-be situation (case 2).

The prototype was presented to a group of 3 policemen who are in charge of organizing the police squadron for keeping public order before, during and after a soccer match in a focus group which lasted for two hours. They evaluated positively the tool in general, especially the possibility of having a graphic overview of what is going on (which justifies the improved AW) and that the tool could contribute to have a unified vision of that (which justifies the improved CV). However, they expressed concerns in making a test in real conditions because it may require time and resource to train the people, which they could not afford.

5. Discussion

We pointed out that geocollaboration is influenced by numerous factors, which we organized in 6 categories and 38 attributes. This complexity necessarily turns the design of geocollaborative systems a demanding task. Developers have to analyze the as-is situation to uncover the relationships between task, workplace, work structure, mobility, awareness, data exchange and so forth. Developers also have to conceive and project the to-be scenario through design interventions. And since design is a cyclic open venture, designers also have to constantly assess the quality of the design alternatives.

One important contribution of this research is disentangling the complexity associated with the design of geocollaborative systems. We accomplish this objective by establishing the essential design qualities and supporting a controlled assessment of the design choices. We propose a consistent evaluation framework based on a set of foundational concepts for geocollaboration support taken from the research literature. The framework is based on five indicators: awareness, mobility, proximity, collaborative visualization and geographical references.

The two case studies described in the paper elucidate how the framework serves to outline the current (as-is) work conditions and align the (to-be) design interventions. Of course we emphasize that design is a highly creative activity and thus the proposed framework should not be understood as a way to automate or domesticate ideas. That is the main reason why we avoided a quantitative approach to KI specification, which is typically found in industry.[65] Instead, the framework provides qualitative insights over the problem context and design goals.

The framework challenges developers to come up with ideas to improve design quality. It also raises attention to specific phenomena of interest caused by the technical and human facets of collaboration technology. In particular, we note that attributes like situation awareness, pervasiveness, orientation support, dynamic interaction, and working virtually in the same place are very hard to come together in a single application. The two cases described in this paper show that the framework highlights areas where to improve collaboration support.

Perhaps the most compelling example is given by the awareness KI. The research literature shows that awareness encompasses a large number of features, ranging from the simple and direct hint about who belongs to the group, towards the much more challenging goal that is supporting the projection of emergent situations. The KI reminds implementers to work with diverse elements associated with the collaboration setting in order to improve awareness. But on hindsight we realize that some of the KI – awareness and mobility, to be more precise – seem more far reaching than the others. Future research should address the extension of the other KI to include more challenging attributes.

The framework also offers ample opportunities for benchmarking design options according with a set of clearly defined criteria. Although the five KI cover all categories we found in the literature, we understand that, generally speaking, more indicators could be brought forward. For instance, some additional focus could be given to practical aspects related with the implementation of collaboration technology. Thus one subsequent step of this research would be inquiring practitioners about the comprehensiveness of the framework. Nevertheless, as pointed out by others, having too many indicators may turn it difficult to focus on the important issues while too few may result in distorted action.[58]

We may also discuss some limitations of the proposed approach. A very significant one is that the proposed KI are not accompanied with explanatory advice on how to design geocollaborative systems. The proposed framework could be integrated with design patterns for collaboration support. Some design patterns have already been proposed.[66-69]

Another limitation to consider is that the framework assumes an incremental approach to design. We understand that radical designs would certainly avoid using the framework, most certainly to avoid any reproduction effects suggested by the KI.[65]

6. Conclusions

In this paper we characterize geocollaboration using five key indicators drawn from the related literature: awareness, mobility, proximity, collaborative visualization and geographic relationships. Together, these indicators address a comprehensive collection of technical and human issues raised by the support to geocollaboration.

Based on these indicators, we developed a framework for assessing the design of geocollaborative systems. The framework suggests an iterative approach to design where the as-is and to-be situations are confronted with the five KI. The framework indicates a set of design questions as well as measures required to construct the indicator. The framework is appealing to technology implementers and prospective clients. The former may get a structured approach to objectively compare design options, while the latter may find a simple approach to benchmark the available options.

The framework was validated in two case studies, which involved support to geologists working in the field and the evacuation of crowded places by the police. Both cases lead to functional prototypes. The case studies elucidate the impact of the framework on the design process, providing a simple procedure to analyze the current collaborative setting and to compare it with the redesigned working scenarios.

This research is relevant to implementers in two complementary ways: highlighting important areas where the design of geocollaboration support should focus; and offering a structured mechanism to control the implementation towards the elected design goals.

The KPI do not have an underlying theory if we consider a causal/relationship theory. Similarly to Dix's [33], we build a descriptive theory, which is summarized by Table 1, and use it to develop the KPI. We think that a causal/relationship theory could be built after using the KPI for a long time, as specific patterns could emerge. We regard the evaluation framework as a new IT artifact built according with the propositions of design science. However, this new artifact does not aim to demonstrate utility to the whole application development process. As Hevner says [17], design is a creative search process, where advice may be counterproductive. So we just mechanize what should be mechanized, i.e. the evaluation process. Consequently, we do not argue that KPI seeks to help the design of new tools and applications but instead it seeks to help the evaluation phase. Because of this, the KPI do not provide an externally assessable mechanism to measure design improvements. Our approach is more introspective, i.e. it helps the designer but it is not a mechanism for obtaining external validity. This is because design science is not natural science, where hypotheses have to be validated. Design science proposes an iterative relevance/rigor cycle, not a validation cycle. The KPI help the rigor cycle by leading the designer towards observing the evolution of artifacts according with a set of objective criteria instead.

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