# COLLABORATIVE MAPPING AND SPATIO-TEMPORAL DATA DISSEMINATION THROUGH A WEB-BASED VIRTUAL GLOBE APPLICATION

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*Recent updates in Google Earth, which provide the possibility to couple cartographic animation with real-time information dissemination, make this software suitable for environmental researchers who work with spatio-temporal data and participate on distributed research projects. Even though it seems simple, computer supported group work with geospatial information at a distance requires a careful consideration for the end-users and their interactions as a group. However, user-centered design and empirical evaluations of geo-collaborative applications and web-based virtual globes are still very rare. To fill this gap, a user-centered design approach was adopted in the development of a geo-collaborative web-based virtual globe prototype, designed for distributed teams of environmental researchers working with spatio-temporal data. User requirements were obtained through a dedicated on-line survey and a focus group discussion. Additionally, six collaborative empirical tests with animated spatio-temporal data representations were conducted and analyzed. The obtained results have implications for addressing an emerging critical issue in GIScience software development, namely, designing more useful geo-collaborative web-based tools.*

***Keywords***: *virtual globes, Google Earth, collaborative mapping, geovisualization, usability, user-centered design*

## 1. INTRODUCTION

The need to coordinate efforts in environmental sciences has always been strong and is even more relevant at present when dispersed teams of researchers struggle to extract and communicate useful information from an increasing amount of spatio-temporal data. However, this effort is also very demanding. On the one hand, the gradual shift from only working with spatial to spatio-temporal data (i.e. time-referenced geographic data) allowed scientists to understand better how systems function (Harrower, 2002), but increased the complexity in cartographic representations. On the other hand, current technology is still incapable of providing fully adequate support for people working with geospatial information at the same time, but at different locations (Hardisty, 2009). Furthermore, even though a number of collaborative (groupware) applications were designed and implemented in the last couple of years, none of those is particularly suitable for work with and dissemination of spatio-temporal data.

Recent developments in web-based virtual globe technology, however, seem to provide solutions to this challenge. Also known as 3D geobrowsers (Foresman, 2004) *a virtual globe* is a digital three-dimensional and highly interactive representation of the planet Earth (Blower et al., 2007; Köbben and Graham, 2009). With more than 25 software applications on the market, the most developed and widely accepted application is Google Earth (Blower et al., 2007). In terms of disseminating spatio-temporal data among environmental researchers, the biggest advantages of Google Earth are connected with two recent updates. First, in 2006 the Keyhole Markup Language (KML), originally used for dissemination of geospatial data, was expanded to allow visualization of temporal data through the introduction of two additional tags: <TimeSpan> and <TimeStamp> (URL_1). This update presents a good opportunity for dissemination of spatio-temporal data, because a number of authors identify cartographic animation as one of the most effective means to communicate temporal patterns and dynamics (e.g. Peterson, 1995; Harrower, 2002). Second, a more recent update allows the opportunity to bring together people situated at distant locations. Such distributed collaborative use of geospatial information (often referred to as 'collaborative visualization' or 'collaborative mapping'), has been defined as a committed effort to use visual displays by multiple participants to frame and address a task (Brewer et al., 2000). Distributed collaborative use of geospatial information has gained significant amount of attention in recent years and is also part of the international research agenda (MacEachren and Kraak, 2001).

Visual displays may be utilized in different ways by groups of people (MacEachren, 2001): at the same time/same place and same time/different place (synchronous group activities), or at a different time/different place and different time/same place (asynchronous group activities). The Google Earth plug-in and Google Earth Application Programming Interface (API), officially released in 2008 are already showing a potential to satisfy same time/different place

collaborative activities allowing users to embed a virtual globe within a website and customize it according to their needs (URL_2). Also released in 2008, the application EarthPad allows multiple users to synchronize their displays so that all can see the applied changes. This functionality is coupled with a text-based chat, provided at the bottom of the page. Further, a number of other examples in the Google Earth API gallery show how several Google Earth instances (i.e. displays) can be embedded in a web page, or how the contents of KML can be changed interactively by the user, allowing access to underlying code without the need for special scripting skills.
Brought together, such elements provide the opportunity to combine interactive cartographic animation with rapid real-time dissemination of information in a multi-user environment. In other words, such tools may serve as a two-way communication channel between researchers working with spatio-temporal data on distributed research projects. In terms of multi-user (groupware) applications, however, design and implementation are still connected with a number of technical challenges, such as data exchange, synchronization of the visual displays, etc. In fact, in the last couple of years the focus was placed so much on the technical end that the challenge is no longer to purely show that an idea can be implemented (MacEachren, 2005), but rather to make these and similar tools more useful and usable. This concept brings us to a user-centered design (UCD) approach (van Elzakker and Wealands, 2007).
Although rarely, the UCD approach is already being attempted and reported by authors who design and implement geo-collaborative applications for non-expert users in areas such as disaster and emergency response (Fuhrmann et al., 2008), crisis management (MacEachren and Cai, 2006) or cancer control and surveillance (Robinson et al., 2007). In contrast, significantly less attention is directed towards domain-expert users who work with spatio-temporal data on distributed research projects, where visualization can serve as a mediator for presenting results and coordinating actions. Taking this into consideration, the essence of our research was to outline key user requirements and needs of environmental researchers for distributed collaborative work with animated maps. Accordingly, this paper starts with a general description of a UCD approach and the selected methods for the purpose of this study. Thereafter, we reflect on the results obtained from a dedicated on-line survey, a focus group discussion and six collaborative usability tests. Our results are then subjected to discussion, followed by some concluding remarks and, finally, further research directions with respect to increasing the usability of geo-collaborative web-based applications.

## 2. SELECTED UCD APPROACH

Placing the users at the center of design in order to increase the *usability* of geo-collaborative tools is a very challenging endeavour. This is connected with the fact that the usability of any application can be influenced by a number of factors (Nielsen, 1993). Moreover, *groupware usability*, defined as "the degree to which a groupware system supports the mechanics of collaboration for a particular set of users and a particular set of tasks" (Gutwin and Greenberg, 2000, p.10), relies on the assumption that the system is already usable from a single-user perspective. This makes early focus on individual users essential in design and brings us to one of the main principles behind the UCD approach: to know the user (Nielsen, 1993).

### 2.1. Use case scenario and user profiling

A common starting point in UCD is to identify and describe the different types of users that will be affected by the product under development. Hence, the first stage in UCD, referred to as Requirements Analysis (van Elzakker and Wealands, 2007), includes a description of the users and what they do to achieve their goals, as well as their wishes for future products (Abras et al., 2004). The gathered information can be used for further task analysis and/or can be unified in *use case scenarios* (Nivala et al., 2005). Use case scenarios are "a description of a possible set of events that might reasonably take place" (Jakobsson, 2003). Cooperative (also called collaborative) scenarios are a preferred alternative in the design of groupware as they may easily simulate new functionality, generate ideas (Stiemerling and Cremers, 1998) and can also be used in later evaluation stages with representative users.
In order to keep the focus of our study, prior to all design activities a generic use case scenario was developed. Key collaborative and individual user tasks were identified, based on relevant literature including visualization of geospatial data (e.g. MacEachren and Kraak, 1997), work and interaction with animated maps (e.g. Ogao, 2006), and collaborative use of geospatial data (e.g. MacEachren, 2001). The generic scenario was compiled in a simple text form and later extended through the results of an *on-line survey*, specifically dedicated to gather data on key user characteristics.
The main aim of the on-line survey was to collect qualitative information about the primary user group on key demographic, physical and psychological characteristics, their work with spatio-temporal data, as well as their current ways and needs for collaboration. The survey was administered through a hyper-link generated by SurveyMonkey (URL_3) and distributed through an invitation letter to environmental researchers at the University of Twente.

### 2.2. Interface design

Despite the general lack of principles to guide the design of a collaborative environment for dissemination of spatio-temporal data, a number of principles for single-user applications were adopted. Considering the special purpose of the application, design elements that formed the user interface were guided by principles and recommendations directed towards single-user interfaces that supply interaction to animated maps (e.g. Harrower, 2003), general usability heuristics for interface design (Nielsen, 1994) and specific groupware usability heuristics (Baker et al., 2002).

## 2.3. User feedback

After capturing initial user requirements through use case scenarios and/or detailed task analysis, the next step is to make the first design implementations (Nivala et al., 2005). Such efforts are based on a number of assumptions which can be further dispersed or confirmed through evaluation with representative users. For the sake of time and resources, user feedback and evaluation is often based on a prototype (a limited version of the system) which can be used in a *focus group* discussion. Being collaborative in nature, focus groups are a research instrument for collecting qualitative data in early design stages. A similar approach was adopted by Harrower et al. (2000) to identify "unintended variables or distracting interface flaws" and was also chosen in this study.
In order to increase the output from the focus group discussion, a *trial exploratory interview* was scheduled with a domain-expert, identified as a representative user through the results from the on-line survey. Trial exploratory interviews are a common method to adjust scripts and procedures used in focus groups (Morgan, 1998). Consequently, the focus group discussion was organized with six participants, identified as representative users through the results from the on-line survey. This number is generally considered optimal for the purpose of the meeting (Nielsen, 1993). During the focus group discussion, domain experts were exposed to the design of the application and the developed generic scenario, encouraged to ask questions and prompted to discuss and evaluate the planned functionality. They were also requested to give recommendations for further improvement.

## 2.4. Prototyping

Implementation of a working *prototype* was carried out by a software developer. In the course of design and re-design activities, sample code in the Google Earth API gallery was examined to review the elements that would suit best already identified user requirements. A number of those were used, and can be found on: URL_4, URL_5, URL_6, URL_7, and URL_8. Further, several possibilities were discussed with the software developer with respect to various collaborative aspects of the application. The final choice fell on the web application framework Ruby on Rails (URL_9), since (Thomas and Hanson, 2005; Lewis et al., 2007): 1) it is open source; 2) it allows fast development and re-design of web applications; 3) it supports web services, AJAX, XML-code generation, and JavaScript Object Notation (JSON); 4) it has excellent libraries and provides support for collaborative processes and 5) it can be extended to handle geometric data types, as well as various input and output data formats (e.g. KML, GeoRSS, shapefiles) through the plug-in GeoRuby (URL_10).

## 2.5. Usability testing

While focus groups probe mainly for users' opinions and feelings, iteratively throughout the UCD cycle usability tests, expert evaluations, or on-site observations allow designers to obtain data related to user interaction and performance with the product (Nielsen, 1993; Abras et al., 2004). Although yielding comprehensive data, field studies may take a considerable amount of time. For instance, Steves et al. (2001) conducted a field experiment to evaluate the usability of a collaborative application for a welding research team which took approximately 10 months to conduct and analyze. Alternatively, Fuhrmann and Pike (2005) discuss video conferencing and desktop sharing as a way to test geo-collaborative tools. Both of these methods, however, require installing special equipment or software packages in order to monitor remotely all participants in the tests. For these reasons, *usability tests* are often conducted in usability laboratories where experts assess the performance of representative users based on a preliminary set of quantifiable or qualitative usability measures. Techniques to complement such usability testing often include (Abras et al., 2004): 1) thinking aloud (users verbalize constantly their thoughts), 2) videotaping (users are recorded with a video camera), 3) screen-logging (the interactions of the user with the interface are recorded) and 4) follow-up interviews.
To date, very few efforts to test the usability of geo-collaborative applications, let alone collaborative virtual globes, are being reported. Only two studies (Jankowski and Nyerges, 2001; Robinson, 2008) document an empirical evaluation of maps as mediators for group work. Unfortunately, both of these examined the use of maps in same time/same place collaborative experiments. Due to this lack of precedents, a number of challenges had to be addressed in an effort to test and observe actual user performance with the developed prototype.
In total, 12 users participated in 6 collaborative tests. Six test sessions were considered suitable for the purpose of the study, having in mind that already 5 test sessions can reveal around 85% of the usability problems within an application (Nielsen, 2000). As described by Cook et al. (2005), it is particularly important to control and isolate independent variables in collaborative experiments, which include, among others, variation in team size, as well as individual roles. Accordingly, particular care was taken to isolate the variance between and within the groups. All users that participated

in the usability tests were similar in rank (each group comprised of one lecturer/assistant professor and one M.Sc. student). All users were unfamiliar with the tool, and did not know each other before the tests.
In the beginning of each test session both participants were introduced to each other and, thereafter, to the purpose of the experiment through a slide-show. A training session with the prototype, coupled with *think-aloud* exercises, preceded the actual evaluation. In each test session, test persons were asked to put themselves in the place of two fictional characters (Simon/Silvia and Bert/Berta) and discuss their planned or actual results on the "Future Land Cover" project simulated in the previously developed scenario. The animated map, which Bert/Berta had to present to Simon/Silvia, comprised of 8 10-day composite NDVI images: 7 NDVI images for April, 1998 and 1 NDVI image for September, 2000. The NDVI image for September differed from the rest of the images. The individual frames in the animation were pre-processed in ArcGIS and exported as a KML file. When done with their tasks, the users were asked about their experience with the prototype in a *follow-up interview* which was conducted in the usability laboratory.
The means to collect the data with were already partially available in a dedicated usability laboratory specifically equipped for think-aloud sessions (van Elzakker, 2004). The laboratory is equipped with a computer and a video camera which captures the user's movements (*Figure 1.A*), as well as a digital quad unit, which synchronizes the signals from several input sources (changes on both computer screens, video of Simon/Silvia and audio of the thinking aloud of both users). The digital quad unit is connected to a TV screen where the researcher could monitor the work of both users during the experiment (*Figure 1.B*). In order to simulate a real "same time/different place" collaborative situation, in addition to the usability laboratory, a specially prepared room was used where one of the users (Bert/Berta) was situated. This room was close to the usability laboratory and was equipped with a mobile video camera and a computer where the user could work with the prototype (*Figure 1.C*).

A B C

*Figure 1 Physical set-up of the usability tests: A. The computer of the user (right) and the video camera (left), which records his/her movements in the usability laboratory. B. The digital quad unit (bottom left) in the usability laboratory, audio/video recorder and TV. C. Additional room with a mobile video camera to capture Bert/Berta's computer screen*

## 3. RESULTS

### 3.1. User profile obtained from the on-line survey

In total, 43 researchers participated in the on-line survey. From them 14 (32,6%) were PhD-candidates, while the remaining 29 (67,4%) were senior researchers, lecturers, assistant or associate professors and professors. The input of only 31 participants, who work with spatio-temporal data and participate in distributed research projects, was taken into consideration (4 participants had skipped most of the questions, while 8 users work only with spatial data).
Results obtained through the on-line survey were analyzed qualitatively and show consistency of basic user characteristics, related to the use of information technology and web-based virtual globes. Ninety percent of all users specified that they currently use Google Earth, half of which make use of the application at least once a week. Users were also similar with respect to experience with, frequency and purpose of use of computers and the Web.
Results showed that the main difference between users is, firstly, in the type of data they use, secondly, in the frequency of communication between users involved in distributed research projects, and finally, in the purpose of collaboration. To expand on this, the spatio-temporal data used by domain experts in the exploratory and analysis phase of research are mostly satellite images and/or maps but these are complemented by additional statistical, ground measurement or vector data. Further, the results show that the products from research that need to be presented to team members vary more than expected and include spatial averages, 3D and subsurface models, but also non-spatial data representations such as graphs and text.
Depending on the purpose of collaborative activities carried out during a research project, respondents can be divided into two main groups. In general, when work is dependent on someone else working on the same project, the utilized

means for communication vary, ranging from personal meetings to specialized software. The frequency of communication ranges from every day to no less than several times a month. Alternatively, when work on a research project is independent, users prefer personal meetings and e-mail as a means for communication. In this case, the frequency of communication is irregular and varies from once a month to no less than every three months.

### 3.2. Designing for the user

The obtained results from the on-line survey and the developed generic scenario allowed implementing the first design alternatives. Planned functionality included: to provide the user with an option to choose and/or create a working research project; provide the user with an option to create and/or choose a virtual room where discussion takes place; spatial and temporal synchronization of the visual displays among two or more users; options to convert different data into KML format, etc. The design and organization of the interface elements followed the general and groupware usability heuristics, mentioned previously.

### 3.3. User feedback obtained from the focus group discussion

The trial interview and the focus group discussion generated more suggestions towards the collaborative aspects of the application under development. Some general suggestions included to provide data exchange options, video tutorials, and help documentation. Additionally, issues in four other areas were addressed:

- **Management of information** – participants found the idea to save the information in a virtual room very useful and required that generated information is organized in an intuitive way through setting a time-span of the history of a virtual room. Another suggestion was to find a suitable way to organize the rooms in a project in order to minimize confusion if their number increases to more than one hundred.
- **Accuracy and scale** – several participants voiced their concern about accuracy and scale. As users noticed, accuracy is lost when converting files to KML. Additionally, users noted the potential risk that the application would not suit the needs of researchers who work on environmental research projects that require small scale representations.
- **Privacy level** - the interviewee and the participants in the focus group discussed various levels of privacy and security. All of them agreed that the future users of the platform should be provided with different access level to 1) projects, 2) datasets, 3) rooms, and 4) visual display content. For instance, there was a suggestion that users are provided with an option to set the status of a virtual room either to “private” (visible only to particular project members) or “public” (visible to everybody).
- **Control of display and display settings** – Participants in the focus group found the option to hand over the control of the display very useful. The interviewee voiced out a concern that a number of conflict situations may arise if an overwrite option over the display is lacking. Another suggestion with respect to the settings of the display was to provide an option for users to be able to define a “study area” of a project so that they are not forced to zoom in/out every time they enter a virtual room.

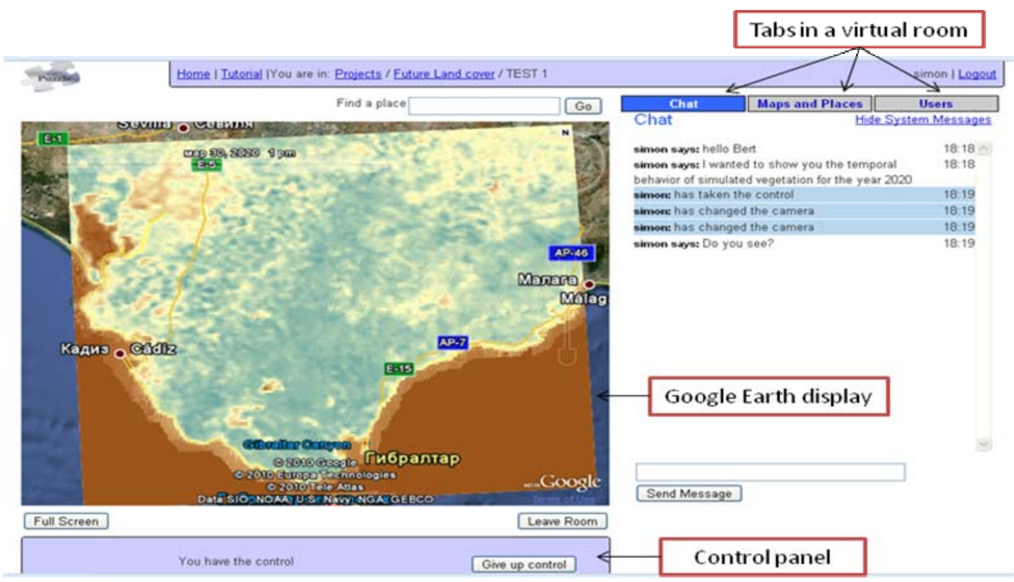


*Figure 2 General outlook of a virtual room, showing the Google Earth display in the left side of the web page, the Chat tab, Maps and Places tab and Users tab on the right and the Control panel in the bottom*

### 3.4. The prototype

The developed prototype, "GeoPuzzle", can be found on URL: http://deni.hostit.bg (optimized to work in Google Chrome). *Figure 2* is an illustration of the interface of a virtual room where discussion takes place. Interested readers are encouraged to register, log into the application and click their way through it.
The implemented functional version of the prototype allows users to upload and edit custom spatio-temporal data or location-specific non-spatial data, such as images or text. Users are able to describe and comment their data in real time with two or more team members. Spatial synchronization of their visual displays provides context for focused discussions, and yet does not prevent individual work. Generated system feedback in the chat window allows the users to monitor the activities in a virtual room and handle the control over the Google Earth display effectively. Support of asynchronous collaborative activities is provided by options to save the chat sessions and system messages, uploaded maps and the last extent and zoom level at which the maps were viewed in a virtual room.

### 3.5. User performance results obtained from the usability tests

Each test session was completed within a time frame of 60 to 90 minutes. A task was considered finished if both users carry out the indicated activities in the instructions and are able to answer the associated questions. Even though the degree of details varied, in general all users were able to provide answers to the questions. In terms of general organization and language, all users were comfortable with the interface. No problems were observed when uploading animated maps, filling in name and comments for each animated map. Users were able to recollect immediately where to invite temporarily another user to a virtual room or download the already uploaded maps. All users were very comfortable with the text-based chat. Text subjects did not have problems when navigating inside the Google Earth display. Most of the times this happened either through the mouse scroll wheel, or by clicking inside the Google Earth display and dragging it to change the view. Several users preferred to make use of the navigation bar when zooming in or out, however, none of the other "joysticks" provided by the Google Earth plug-in were used.

The test sessions revealed a core of similar usability problems**,** such as:

- In three of the groups Simon/Silvia did not see the temporal legend when their partner uploaded and displayed the animated map. In the first two cases the researcher decided that this is due to inappropriate instructions and interfered. However, in the third case this situation resulted in the user not playing the animation.
- In group 3 the users were speaking about dramatic changes in the territory; however, they were discussing different frames of the animated map, which resulted in confusion.
- In several groups Simon/Silvia did not know immediately where to find the description of the uploaded map and its title. Although these are available in an additional tab (situated next to the Chat tab), the users did not look at them. System messages for the title of the map do not give much clue about what is represented.
- Lack of awareness of the actions of the other user leads to discomfort. Not knowing when the other person is typing or switching between tabs did not hinder collaborative work but resulted in confusion among users.
- When trying to find a location, the users did not use the search bar even if this was their intention.
- In three groups the user forgot to take control before showing a location to his/her partner. The users recovered quickly from the situation. This accounted to the fact that normally Bert (or Simon) would ask in the Chat tab "*Do you see the location*?".
- Another minor problem was that in several groups, the users were simply trying to rewind the animation, ending up with changing the time range for the animated map.

In order to compare the use of animated maps between group members and between groups, their actual use during the evaluation was recorded. However, no obvious pattern could be distinguished between group members in different groups. Even though in the beginning of each session the users watched the animated maps without jumping to particular frames, this strategy changed in the course of the "virtual meeting". Users either continued to look at particular frames through the time slider, using the arrows in the temporal legend, or watched several times the animated maps from start to end. Only few of them changed the speed of the animation. In other words, users' actions did not have any visible order and were connected with the discussion at hand.
All users provided positive feedback after completing the evaluation and agreed that such a tool would be useful and complement other collaborative applications (e.g. voice chat or e-mail). Suggestions for improvement were directed towards increasing the awareness between users as well as provision of an audio chat.

## 4. DISCUSSION

### 4.1. User profile

Findings from the on-line survey implied that, when domain experts are considered, basic user characteristics are not indicative of user differences that the design should accommodate. In other words, users were very similar in terms of experience with computers and web-based virtual globes. The implication from this finding is that the application under development should employ standard web and virtual-globe terminology and organization of the interface.
Difference in utilized data in analysis as well as the resulting products to be communicated to team members requires design and implementation of different functionality, specific for the data at hand. A major repercussion for future development was to separate functionality specifically directed towards creating animated representations and changing their settings in a separate module. Finally, the difference in purpose and frequency of communication on a research project influenced both the design, as well as the usability criteria that the prototype was to accommodate. Irregular and less frequent communication on research projects defined learnability and memorability as main criteria determining the effective use of the application under development.

### 4.2. User feedback

Results from the interview and the focus group discussion are specific for the explored user group in this study and can further complement previously identified key system characteristics, such as private work and drawing the group's attention, also discussed by Brewer et al. (2000). Comparing these system characteristics with the list of identified user requirements in this study, it becomes clear that user requirements are dictated not only by difference in individual user characteristics, but are also tool- and task- specific.

### 4.3. User performance

The six collaborative usability tests revealed a core of similar problems that users experience. Confusion with the organization of the initial modules of the platform implies that particular care needs to be taken of the organization of information within the prototype in order to make it more intuitive for users. Individual problems with the search bar confirmed previously identified usability problems with respect to its position above the map display. To alleviate this problem, it is recommended that the position of this element is re-considered in the future and placed under the map display. This is the place where users were trying to locate it during the test sessions.
As reported in the results section, the lack of awareness for users' actions led to several problematic situations. It was observed that users were not comfortable when the system did not provide feedback on their partner's actions. Additionally, confusion arose in several groups, where the users forgot to take control before showing a location to their partners. While these problems did not have any serious effect on the outcome of the test, in one of the groups the users ended up discussing the same territory but different frames of the animation.
The need to represent users and their behaviour has also been discussed by Brewer et al. (2000). When it comes to geo-collaborative applications, apart from explicit representation of participants, there is a need to add awareness of how users are interacting with the data representations. This argument is further supported by the findings of this study and is even more relevant when it comes to work with animated spatio-temporal representations in view of the outlined situation. One possible solution would be to fully synchronize the visual display among users both in the spatial and temporal domains. This may also help dealing with a situation in which one of the users does not notice the temporal legend and is not immediately aware that the represented data are animated. Hence, finding a way to synchronize the visual displays in the spatial, as well as in the temporal domain is strongly recommended if further work is intended.
Full spatial and temporal synchronization of the visual displays, however, would also impede work to a certain extent. As observed previously (e.g. Blok, 2005), users apply different strategies to view and interact with animated maps, which is further confirmed by the obtained results in this study. Here, however, it was expected that users who have information about the animated maps and are not required to gain new or additional knowledge from it, would interact with it less. However, this was not the case. Strategies and the level of interaction with the animated representations differed among users without any clear pattern. One possible explanation is that such interactions are related to the discussion at hand. This observation implies that, in terms of synchronization, users should be able also to desynchronize their displays in order to view and interact with the animated maps individually, without disturbing the work of their partner.
In addition, separating content regarding the maps (including title, legend, and description) from the visual display had a negative effect on collaborative work. As observed, the decision to separate key map elements from the map display was found not suitable, even when this information is communicated through a text-based chat in real-time. This was confirmed by the observation that, in almost all collaborative sessions, users did not make use of the provided information in the Maps and Places module. A possible solution is to provide this information in the map display as well.

## 5. CONCLUSIONS

This research reports on the design and user evaluation of a geo-collaborative web-based virtual globe for dissemination of spatio-temporal data through a holistic user-centered design approach. In doing so, results from all UCD design stages were reported. To sum up, as part of the requirements analysis stage, results show that, as opposed to age, skills and abilities which are often advocated as most influential upon design in usability engineering literature, of main concern here is the variety in data among users, the purpose of collaboration and frequency of communication. Implications for design include planning for and implementing functionality specific for the data at hand.
Requirements elicitation was complemented by early user feedback, which provided also an opportunity to identify further user needs and, what is more, possible barriers for collaborative work. When it comes to effective dissemination of spatio-temporal data in a multi-user environment there is a need for effective management and query of information and content within a project or a virtual room. Secondly, in terms of privacy, a requirement is to provide an option to set different access levels to projects, datasets, rooms and display content. Finally, it is required to provide access to the settings of the Google Earth display and overwrite/time-out options of its control.
Usability testing of the developed prototype revealed no severe problems with organization or language of the interface. The main shortcoming of the current functionality offered by the Google Earth API in terms of presentation of spatio-temporal data in a collaborative environment is the lack of possibility to synchronize fully the display between two or more users in the temporal domain. This is a serious limitation and prevents an adequate execution of work with animated maps during same time/different place collaborative work. Finally, it is noteworthy that due to the qualitative nature of the conducted empirical experiments, the presented results are tool- and task-specific but can serve as a stepping stone for further research of both qualitative and quantitative nature.
The elicited user requirements and identified advantages and disadvantages of web-based virtual globes are only a small step towards improvement of collaborative mapping and spatio-temporal data dissemination for domain experts involved in distributed research projects. In future work, researchers are encouraged to consider more detailed requirements elicitation through background interviews among the members of one, or several research projects, as well as to take into account different collaborative scenarios during usability testing.

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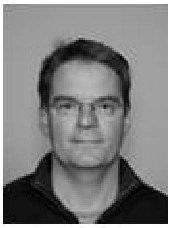

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