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User requirements for geo-collaborative work with spatio-temporal data in a web-based virtual globe environment

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ABSTRACT

Web-based tools developed in the last couple of years offer unique opportunities to effectively support scientists in their effort to collaborate. Communication among environmental researchers often involves not only work with geographical (spatial), but also with temporal data and information. Literature still provides limited documentation when it comes to user requirements for effective geo-collaborative work with spatio-temporal data. To start filling this gap, our study adopted a User-Centered Design approach and first explored the user requirements of environmental researchers working on distributed research projects for collaborative dissemination, exchange and work with spatio-temporal data. Our results show that system design will be mainly influenced by the nature and type of data users work with. From the end-users' perspective, optimal conversion of huge files of spatio-temporal data for further dissemination, accuracy of conversion, organization of content and security have a key role for effective geo-collaboration.

1. Introduction

Fast, timely and effective communication among dispersed members of research teams is no longer a luxury but one of the fundamental requirements for the completion of a research project. Web-based tools developed in the last couple of years offer an unprecedented opportunity to support environmental scientists in their effort to collaborate. In particular, many groupware tools such as e-mail, text-based and audio chat, video conferencing tools, and whiteboards provide the opportunity to facilitate distributed communication and collaborative work. However, the nature of collaborative work with geographical data, also termed geo-collaboration, is different from other collaborative activities. Geo-collaboration is defined as the use of a visual display (often some form of a map) by two or more participants to frame and address a problem or to complete a task (MacEachren, 2001). There are four different ways in which geo-collaborative activities can take place: same time/same place (face-to-face interaction), same time/different place (synchronous distributed interaction), different time/same place (asynchronous interaction) and different time/different place (asynchronous distributed interaction) (MacEachren, 2001; Haklay, 2010). In this study the main focus was on synchronous and asynchronous distributed interaction.

Developing and designing collaborative applications (groupware) for distributed collaborative work is very challenging, due to a number of technical and sociotechnical (user) issues that have to be addressed. In the past, disregard of the latter often led to collaborative systems being rejected by their intended users (Murray and Hewitt, 1994). The same holds true for geo-collaborative tools (MacEachren, 2005). Here the challenge is even higher, as the application designer has to take into account domain-specific issues, not discussed by traditional Human–Computer Interaction (HCI), Usability Engineering (UE) or Computer Supported Cooperative Work (CSCW) literature. As a result, User-Centered Design (UCD) now forms part of the international research agenda (Virranteus et al., 2009) and is becoming more popular among GIScience researchers (van Elzakker and Wealands, 2007; Haklay and Nivala, 2010) and developers working within the field of geo-collaboration (Fuhrmann and Pike, 2005). An example is the development of the "Argumentation Map", during which a broad range of technical (Rinner, 2001; Keβler et al., 2005) and user (Sidlar and Rinner, 2006, 2009) issues with the design of geo-collaborative platforms emerged and were documented. This case demonstrated the need for a deeper understanding of the users and their needs and only thereafter develop functionality that facilitates rather than hinders their work. Recently, there have been a number of other successful examples of applying UCD to the development of

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geo-collaborative tools. However, the current research focus within the area of geo-collaboration gradually shifted towards exploring the needs of a broad range of non-expert users (Koua et al., 2009) within the fields of disaster and emergency response (Fuhrmann et al., 2008), crisis management (Cai et al., 2005; MacEachren and Cai, 2006), or other similar fields.

The work presented in this paper builds upon previous research within the field of geo-collaborative work, but was directed towards the specific needs of environmental domain-expert users that form part of distributed research projects. Collaboration among environmental researchers often involves not only the exchange of geographical data, but also dissemination of temporal data and information. In this paper we use the term *spatio-temporal data* to designate geographical data with a temporal component (reflecting changes and/or processes over an area for a period of time). When represented effectively and users attaching a meaning to them, such data are turned into *spatio-temporal information*.

Geographical data that contain a temporal component increase the complexity of traditional cartographic representations and instigated the development of various novel visualization techniques, including time–series graphs, temporal glyphs, small multiples and the space-time cube. The scientific process of looking for an optimal solution is still underway (Virranteus et al., 2009). However, a number of authors identify cartographic animation as one of the most effective means to communicate temporal patterns and dynamics (e.g. DiBiase, 1990; Peterson, 1995). Often referred to as *dynamic*, or simply *animation*, an *animated map* is a series of individual maps that are shown in quick succession, creating the illusion of a change (Peterson, 1995). Interface design for animated maps is unique and requires special considerations (Harrower, 2003). Literature still provides a limited number of reports examining the requirements of domain-expert users for collaborative work with animated cartographic representations. Having this in mind, the objective of our study was to explore user requirements of environmental researchers working on distributed research projects for collaborative dissemination, exchange and distributed work with spatio-temporal data.

The recent proliferation of groupware tools, web mapping platforms and Application Programming Interfaces (APIs), and web-based virtual globe technology (e.g. Google Earth, MS Virtual Earth) allow for the fast evolutionary development of geospatial tools that are relatively easy to implement. One of the most prominent examples is the three-dimensional and highly interactive web-based virtual globe Google Earth (Blower et al., 2007; Köbben and Graham, 2009). This geobrowser allows navigation through a vast amount of on-line spatial data and seems potentially suitable to satisfy the needs of environmental researchers for collaborative work through two recent updates in the functionality it offers. On the one hand, the release of the Google Earth API and plug-in allows for the embedding of the virtual globe inside a web browser and the support of various collaborative activities, such as real-time communication and synchronization of the visual displays among users. An example is the collaborative application EarthPad developed by Carl Nygaard (Google Earth, 2012). This development allows for fast implementation of a lightweight geo-collaborative tool that is widely accessible from a simple web browser. On the other hand, the Keyhole Markup Language (KML), originally used for the dissemination and visualization of geographical data in Google Earth, was updated to support spatio-temporal data. This was achieved through the introduction of two additional elements in the KML syntax (<TimeStamps> and <TimeSpan>), which allow for definition of time values of features (Google, 2011). Additionally, KML is supported by a number of virtual globes and GIS applications and quickly became a "de facto" standard (Blower et al., 2007) for geospatial data dissemination, even before being adopted as an OGC[1] standard in 2008. Making use of such recent developments, this study focused on the use of cartographic animation (in KML format) for real-time distributed work with spatio-temporal data within the Google Earth web-based virtual globe environment.

To achieve the objectives of our study, a User-Centered Design approach was adopted. Section 2 describes the essential principles for UCD and the methods for user-centered requirements engineering. Further, Section 3 gives a short review of the selected methods for the purpose of this study and a description of the undertaken procedures. Thereafter, we present (Section 4) and discuss (Section 5) the results of our work relating to the obtained user characteristics, preferences and feedback that influenced user requirements with respect to the effective use and dissemination of spatio-temporal data within a collaborative web-based virtual globe environment.

2. Usability and requirements engineering

Placing the users at the center of design in order to increase the usefulness of a product or geo-application requires a UCD approach (Abras et al., 2004; van Elzakker and Wealands, 2007; Haklay and Nivala, 2010). UCD is a broad term describing design processes in which end-users' characteristics, needs and context of use influence and shape out the design of a system under development (Abras et al., 2004). The main aim is that the product satisfies user requirements, related either to its utility (functional requirements) or its usability.

2.1. Groupware usability and types of User requirements

From a user perspective, non-functional usability requirements may be critical in determining the successful use of an application (Maguire, 1998). The same principle applies for geo-applications and is even more relevant for geo-collaborative tools (MacEachren, 2005). When it comes to groupware, usability is "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. 100). According to the same authors, the *mechanics of collaboration* include several specific processes: explicit and consequential communication, coordination of action, planning, assistance and protection. Assessing the usability of multi-user systems, therefore, means to measure how effective, efficient and satisfactory a system is in supporting all of these processes (Gutwin and Greenberg, 2000). The above definition reveals why eliciting user requirements and increasing the usability of groupware is a significant challenge. The definition relies on the assumption that a system is already usable from a single-user perspective. This brings us to one of the main principles of UCD: early focus on individual users.

2.2. Selected requirement gathering methods and procedures

In general, there is a lack of a single unified framework for conducting UCD (Gulliksen et al., 2003). Therefore, designers dispose of a broad range of techniques and alternatives, the final choice of which eventually depends on the nature of the system being designed, the available resources and time, as well as the research objectives. In an overview article, Haynes et al. (2009, p. 333) suggested that, "the different perspectives gained from

[1] OGC – Open Geospatial Consortium – a non profit, international, voluntary consensus standards organization that is leading the development of standards for geospatial and location-based services.

multiple evaluation may be better equipped to address the inherent complexity of collaborative systems". In this study a three-stage iterative process, comprising of requirements analysis, design, and evaluation (Elzakker and Wealands, 2007; Haklay et al., 2010) was adopted. The selected methods form part of commonly applied methodologies, recommended within HCI (Mayhew, 1999), UE (Nielsen, 1993), CSCW (Haynes et al., 2009) and geo-collaborative (Fuhrmann and Pike, 2005) literature.

In order to explore user requirements, the first issue to investigate was the difference in user characteristics, tasks and preferences from a single-user perspective (see also Section 2.1). Early requirements elicitation often involves methods such as questionnaires, interviews, observations and ethnographic case studies, which result in a description of what users currently do to achieve their goals, as well as their preferences for future products. Prior to committing to more time- and resource-consuming data collection methods, an online questionnaire survey was used to capture important information about the potential user group. Even though the selected approach is highly prone to errors it helps in acquiring focused data on attitudes, facts and user behaviors in the early stage of a project (Belani et al., 2005). Research that makes use of surveys in order to determine user characteristics, perceptions and current (collaborative) problems similar to the approach undertaken in this study has been designed and implemented by Wealands et al. (2007).

The data obtained through the on-line survey were examined carefully in search of emerging patterns. The raw responses from individual participants were first reviewed and compared to the whole dataset. Later, participants were grouped according to similarities in the use of spatio-temporal data, the resulting products from analysis, and the purpose and frequency of collaborative activities. The similarity among participants helped in identifying generic user types. This information and the additional review of literature was used to generate *scenarios* as a fictional description of user activities that guided the design and stimulated new functionality. Scenarios can also be used for requirements elicitation (van Helvert and Fowler, 2003), as exemplified by Jakobsson (2003) and Wealands et al. (2007). In CSCW, cooperative (collaborative) scenarios are one of the preferred methods to elicit user requirements (Stiemerling and Cremers, 1998). In addition, in combination with personas (Gulliksen et al., 2003) they provide a way for the designer to specify the user group and context of use (and the assumptions thereof) that the design will be directed towards. Within the field of geo-collaborative visualization, scenarios were successfully used by MacEachren and Cai (2006) as part of their GeoDialogue approach which aims at facilitating same time/same place human-Geographic Information System-human dialogue through visual displays. In this study, scenarios were further validated and used at all stages of design and evaluations.

One of the limitations of scenarios is that they do not consider interface design and layout (Maguire, 1998). To address this drawback, after specifying the initial user profile and user requirements, the next step was to make the first design implementations in the form of a *low-fidelity prototype* (LFP). LFPs are widely recommended when it comes to obtaining early user feedback (Nielsen, 1993). In this study, the LFP also served to translate a number of design recommendations for animated map interfaces (Harrower, 2003), general web-based (Nielsen, 1993) and groupware (Baker et al., 2002) usability heuristics into specific design elements. These activities, captured in several revisions of the LFP, were complemented by iterative consultation with the scenario, as well as investigation of available web-based virtual globe functionalities and tools. Apart from making assumptions clear and transparent, an LFP was used in order to stimulate further the dialogue between designers and representative users, as also successfully used by Harrower et al. (2000).

Together with the developed scenarios, the LFP was presented to representative users in a focus group discussion. In a focus group discussion, about six to ten users are brought together to discuss new concepts and identify issues over a period of about 2 h (Nielsen, 1993). *Focus groups* and *collaborative workshops* have been found suitable to explore further user requirements towards future information systems (Maguire, 1998) as well as to validate scenarios (Stiemerling and Cremers, 1998). The script for the focus group discussion was based on the results from an exploratory interview with a domain-expert user. Trial exploratory interviews are a common method to adjust scripts and procedures later used in focus groups (Morgan, 1998). In our study, the individual interview and the collaborative discussion generated useful early feedback, allowed observing how users react to planned functionality, but also validated our scenarios since users were encouraged to reason about their own work. The same method has been used to good effect by Harrower et al. (2000) to identify in-depth user requirements for the geographical visualization tool they developed. The results allowed re-designing the LFP, which was followed by implementation of a *high-fidelity prototype* (HFP).

Iteratively throughout the UCD cycle, *usability tests*, expert-based evaluations or on-site observations allow designers to obtain data related to user interaction and performance with the product. Collaborative scenario-based usability tests are often recommended as the most suitable evaluation method for groupware in the early stages of a project, or when time and resources are scarce (Araujo et al., 2004; Haynes et al., 2009). Adopting this approach, this study concluded with six scenario-based collaborative usability tests, directed mainly towards the functionality and organization of the interface, and actual real-time work with spatio-temporal data (in the form of cartographic animations).

The data from the on-line survey, the suggestions from the interview and the focus group discussion revealed the potential and disadvantages of the Google Earth plug-in and animated KML data from the users' point of view to support real-time group work with animated spatio-temporal data representations within a web-based virtual globe environment.

3. User group, materials and procedures

3.1. User group

The primary user group this research was concerned with consisted of domain specialists with expertise in various environmental fields, including hydrology, geology, geography and ecology. Potential users are involved with processing, analysing and/or visually exploring spatio-temporal data to derive useful information within their field of expertise. Further, a typical representative user is a participant in a multi-disciplinary project conducted by dispersed teams of researchers who need to keep in touch for progress reporting. This effort requires and/or may be facilitated by collaborative work in a multi-user environment that supports visualization and dissemination of spatio-temporal data where scientists will be able to exchange knowledge and contextualize their work.

3.2. Questionnaire design and on-line survey setup

Key user attributes that influence the use of a product include (van Elzakker and Wealands, 2007; Nielsen, 1993): age, gender and language (demographic characteristics), sight problems, disabilities (physical characteristics), attitudes, motivation, preferences (psychological characteristics), relevant knowledge in the application domain, education and profession (skills and abilities). All of these will affect user requirements to some extent. However, they may not be indicative of user differences which the design should accommodate when it comes to collaborative use of spatio-temporal data. Unfortunately, the characteristics of the selected users have not been studied and reported extensively in literature. Therefore, in order to collect such user-related data, a dedicated questionnaire was designed, following the recommendation by Mayhew (1999), Belani et al. (2005) and specific examples in similar studies (e.g. Wealands et al., 2007). The main aim was to collect qualitative information about the primary users on key demographic, physical and psychological characteristics, their work with spatio-temporal data, and current ways and needs for collaboration. In view of that, it was decided that gathered information had to pertain to several categories of attributes: 1) Basic user characteristics related to demographics, background knowledge and education, domain expertise, as well as experience with information technology and web-based virtual globes; 2) Current work with spatio-temporal data and animated maps, and problems with their dissemination; 3) Collaborative work, frequency and purpose of communication on research projects; 4) User preferences towards collaborative tools and ways for dissemination of spatio-temporal data; 5) Personal information for further contact and willingness to participate in other stages of research. A total of 37 questions was included in the questionnaire, a sample of which is presented in Table 1. These items were selected in order to facilitate the process of compiling a more thorough user profile. Pilot testing of the questionnaire with a set of potential users of the system (MSc students enrolled in a Geo-Information Science and Earth Observation for Environmental Modelling and Management programme) allowed refining of the questions and re-wording where appropriate.

An on-line survey was used as an instrument to collect data and administer the questionnaire. The questionnaire was distributed to potential users through a hyper-link generated by SurveyMonkey.[2] The hyper-link was sent through a personalized invitation letter to researchers in four departments (Water Resources, Earth System Analysis, Natural Resources, and Earth Observation Science) employed at the Faculty ITC of the University of Twente in Enschede, the Netherlands. A number of additional actions were undertaken, advocated by Kumar (2005) and Nielsen (1993), to deal with limitations often associated with questionnaires and surveys. These are described in Table 2.

3.3. Focus group setup

In the second stage of this study, the identified user requirements towards spatio-temporal data and information were translated into specific design elements through the development of the LFP, illustrated in Fig. 1. In essence, each virtual room has a map display (the Google Earth plug-in), which is synchronized for all viewers through the Control button. On the right side of the webpage, functionality is separated in three main tabs: Chat (where users can send messages and receive system feedback and feedthrough), Maps and places (where users can upload user-generated maps/animated maps, comments and metadata) and Users (where users can monitor the participants in a discussion and send a temporary invitation to an external member of the team).

The possible use of the LPF and the scenario were introduced to a set of representative users, providing them the opportunity to describe in more detail their own work. A number of methodological issues and challenges had to be addressed before conducting the discussion. They are described in Table 3, together with the undertaken actions.

[2] Survey Monkey is a web-based survey development platform, used to create, disseminate, collect and analyse on-line questionnaires (www.surveymonkey.com).

Table 1
Examples of questions included in the on-line survey questionnaire.

Category	Question
Basic User Characteristics	• Please, specify your background education and highest degree attained. • What is your field of expertise?
Work with spatio-temporal data	• Do you work with temporal data? (Please note, that "temporal" here refers to data for different moments in time (e.g. two or more remotely-sensed images, maps, vector or statistical data for the same area but for different periods in time). • Please complete the following sentence: "In my work, the input data used during analysis, most often are:…"
Collaboration	• In your work, are you currently part of any project that involves work with people in another country, city or institution? • How do you establish contact with such distributed teams (other researchers and people working on the project)?

An individual exploratory interview was scheduled before the focus group discussion with a key representative user. The interview provided a good opportunity to address other limitations connected with focus groups (Table 3) in general. The interview took place approximately one week before the focus group. It lasted little more than 40 min and was recorded with a voice recorder. Afterwards, the recording was transcribed for further analysis. The final result was a thick ethnographic description (Morgan, 1988) of the obtained data, which allowed expanding and validating the preliminary scenarios, but also brought up a range of relevant issues that need to be considered during design, as discussed further in Section 4 below.

The focus group discussion took place at the Faculty ITC. It was conducted with 6 key representative users (Table 4). For the purpose of the meeting, a specially prepared room, where several tables and chairs were situated in front of a wall-screen, was used (Fig. 2).

The meeting began with a short presentation, describing the objectives of the study, the schedule, and the purpose and ground

Table 2
Limitations of questionnaires and on-line surveys and undertaken actions to minimize them.

Methodological challenge	Undertaken action(s)
Low response rate	• Questionnaire administered on-line through a hyperlink to SurveyMonkey • Shorten the length of questions and answers
Participants may not understand the questions	• The questions were designed to be simple and self-explanatory and trialled before the survey was conducted • Additional explanations were added for specific terms, which may cause ambiguity, such as "virtual globe", "temporal", "static maps", "animated maps" and "animation" • An animated map was included as part of the questionnaire in order to make sure that all participants understand the term "animation" in the same way
Participants may give confusing responses	• Most of the questions were closed-ended with a predefined range of possible answers • An additional field was added to most questions where the participant could explain his/her answer
Bias in responses	• A category "other" was added to all questions with predefined sets of answers, where a participant could provide his/her own answer
The result cannot be generalized for the whole population	• No action undertaken. This is common for qualitative research and was considered appropriate for this study

Fig. 1. A virtual room in the low-fidelity prototype GeoPuzzle.

rules of the discussion. Additionally, each user had a document containing key points from the presentation and purpose of the meeting. Afterwards, the experts were exposed to the design through the personas and the scenario. Thereafter, the meeting transformed naturally into a discussion. Participants were prompted and encouraged to ask questions, discuss and rate key elements of design, separated in six main categories: 1) work with spatio-temporal data/during a virtual meeting/; 2) creating animated maps on-line; 3) tasks during a virtual meeting; 4) privacy issues; 5) conflict situations; and 6) overall impression of the prototype.

Table 3
Methodological issues that had to be addressed before the focus group discussion.

Methodological issue	Undertaken action(s)
No time to let participants "play around" with the prototype	• The link for the prototype was sent to participants, allowing them enough time to explore it on their own • Encourage participants to work with the prototype before the discussion takes place • Trial interview conducted where the participant was encouraged to work with the prototype
Individual feedback in focus groups is limited	• Trial interview allowed exploring in more detail the individual reactions and feedback of a key representative user • The researcher encourages all participants to express their individual opinion during the focus group discussion
Several focus groups needed to evaluate design	• Not relevant for this study as the focus group discussion was conducted with key representative users • Maximize user diversity in the focus group
Focus groups are difficult to handle	• Focus group adjusted and trialled after the interview

3.4. Collaborative usability tests setup

The implementation phase of a high-fidelity prototype was carried out by a software developer and was followed by six scenario-based collaborative *usability tests*. The main objective of the experiments was to simulate a real distributed same time/different place geo-collaborative situation and to observe how potential users work with the developed prototype. The usability

Table 4
Participants in the focus group meeting.

Researcher	Research expertise	Work with cartographic animation
1	Natural resource management	Creates and uses animated maps
2	Hydrogeology	Works with ready-made animated maps
3	Natural resource management, climate change, forestry	Works with ready-made animated maps
4	Landslide hazards and hill-slope processes	Creates and uses animated maps
5	Soil erosion and remote sensing	Does not work with animated maps
6	Soil erosion modelling	Does not work with animated maps

Fig. 2. View of the focus group meeting setup.

tests took place in a usability laboratory, equipped with a computer (with screen logging), video camera, wireless microphone, and a second room, equipped with a mobile video camera and a computer (Fig. 3). A digital quad unit in the usability laboratory was used to merge and synchronize the input from all sources. In total, twelve representative users participated in the tests, in groups of two. The participants in each group did not know each other prior to the test sessions. Their characteristics are outlined in Table 5.

Each of the six sessions consisted of an introduction, training with an interactive video tutorial, think-aloud session (where users performed tasks according to the developed scenario) and an interview.

The data from the on-line survey, the suggestions from the interview and the focus group discussion, as well as the collaborative usability test sessions revealed the potential and disadvantages of animated KML data from the users' point of view to support real-time group work with animated data representations within a web-based virtual globe environment. These requirements are further outlined.

4. Results

4.1. On-line survey

In total, 43 researchers took part in the survey. Thirty-one of them fitted the primary user profile (Section 3.1). Their answers were further analysed.

All of the participants in the on-line survey are experienced computer users (more than 3 years); make use of the Internet every day (with their main activities being research and communication); and type on a computer keyboard with moderate to very fast speed. Ninety percent of the users specify that they currently use Google Earth, half of which make use of the application at least once a week. Another three users indicated that they have used Google Earth before or have it installed on their computer. There were no indications for use or preference towards another virtual globe, such as NASA WorldWind, ArcGIS Explorer or MS Virtual Earth.

The results from the on-line survey showed that the spatio-temporal data that domain-experts use in the exploratory phase of research (when they try to generate insights from unknown

Fig. 3. View of the usability testing rooms.

Table 5
Participants in the usability tests.

Group	Test person position	Field of expertise	Use of Google Earth
1	Associate professor	Engineering geology	Once a week
	M.Sc. student	Environmental modelling and management	Several times a week
2	Assistant professor	Ecology, GIS, and remote sensing	Once a month
	M.Sc. student	Environmental modelling and management	Rarely
3	Senior researcher	Risk and information management	Several times a month
	M.Sc. student	Environmental modelling and management	Once a month
4	Lecturer	Natural resources management	Once a month
	M.Sc. student	Environmental modelling and management	Once a week
5	Lecturer	Ecology and environmental impact assessment	Several times a month
	M.Sc. student	Environmental modelling and management	Several times a month
6	PhD-candidate	Natural resources management	Once a week
	M.Sc. student	Environmental modelling and management	Several times a month

spatio-temporal data) are most of the time two or more remotely-sensed images or two or more maps. In 87% of the cases, however, spatio-temporal data analysis is supported by complementary data, including vector (representation of reality through discrete features, such as points, lines or polygons) or statistical data. Hence, when analysing their spatio-temporal data, three main categories of users were identified: 1) users of temporal satellite images and/or maps (two or more satellite images and/or maps that show the same area but for different periods of time); 2) users of temporal satellite images and/or maps, together with complementary data, such as vector, statistical or ground measurement data and 3) users of only vector, statistical or ground measurements data. As each of these may become an intermediate product in order to confirm hypotheses with colleagues and generate discussions, functionality should support creating animations from raster (array of cells) and vector (discrete features) maps. Those should be combined with (animated) vector, statistical or ground measurement data.

In general, the output from the users' spatio-temporal data analysis varies much more between users. For instance, only in 35% of the cases the result from the research phase is two or more maps, suitable for animation. Another 35% specify that the output from work with spatio-temporal data is most of the time spatial averages. The rest of the participants note down various outputs, including "graphs", "3D data", "subsurface models", "statistical data" and a "mix of textual, quantitative and qualitative spatio-temporal information". The main implication here is that a virtual real-time meeting between users may not be specifically directed towards work with animated representations, but require additional interface functionality.

It was considered equally important to identify what is the purpose of collaboration, as well as how and how often communication is realized between domain experts. The data obtained through the on-line survey indicated that there is a relationship between the *purpose* of collaboration among researchers, the *collaborative and communication tools* that they use, and the *frequency* with which they communicate. Based on these distinct characteristics, the respondents could be divided into two main groups (A and B).

In the first case (Group A), the work of a domain-expert user is dependent on someone else in a research project. When this happens, users indicate that they use various means for communication and sharing of information, including personal meetings, voice chat, e-mail, dedicated websites or software. The frequency of communication is most regular in this group of users and varies from every day to several times a month. Due to the nature of their work, users in this group would benefit mainly from an exploratory geo-collaborative environment where they can collaboratively formulate hypotheses and analyse spatio-temporal data in real-time. This comes closer to Collaborative Spatial Decision Support Systems (Haklay, 2010). The interface for Group A may include more functionality and diverse design elements, since these users have relatively more experience with groupware tools, and will use the application more frequently. Here, the main usability criteria would be effectiveness and efficiency.

On the other hand, design for users from Group B who work independently and only share progress at regular intervals of time or when their work on the project is finished would differ substantially. Currently, the means of communication in this group are mainly personal meetings and e-mails. Contact is not realized more regularly than once a month. The main implication with respect to working effectively with spatio-temporal data is that the design should provide a simple and fast way to find data immediately. User-generated data and uploaded files should be descriptive and supplemented by metadata. Here, memorability and learnability would be the main aspects that will determine usability.

As expected, the vast majority of domain experts prefer a fast website rendered with basic GIS (Geographic Information Systems) functionality. Even though users did not specify what those functions should be, it was assumed that these may include e.g. measuring distances on the map or intersection of map layers. In this context, one of the users indicated that "both the local and the distant user [should] have the possibility to make changes" in the uploaded data and maps. In terms of uploading user-generated spatio-temporal data, participants expressed the need for tools to add text and comment upon data. Additionally, one participant expressed the need to provide all users in a virtual room with the possibility to upload their results in exactly the same location of a map.

Two other participants expressed the need for customization of the whole application, as well as with respect to the maps themselves, with one participant noting down that there should be a way for the user to upload data that "can be updated in the way of the thinking process". The most frequent other preference was to provide users with tools to comment upon their data and add text to the maps. When this related to comments and adding text to maps, this would also mean associating. Users also expressed the desire to be able to download maps to the user's local drive after discussion takes place.

A number of participants indicated that currently they have a problem with the huge sizes of the files they work with. Consequently, when allowed to make suggestions for the ideal web application, they prefer to be provided with a lot of storage space. Finally, participants also expressed the critical need for restricted access to data and content for collaborators.

4.2. Focus group results

After the focus group took place the recorded video was transcribed manually and was examined thoroughly by the first author in order to obtain fluency with the content. Afterwards, a qualitative content analysis approach (Weber, 1990) was adopted. The transcript from the focus group was iteratively scrutinized based on the thematic framework developed prior to the focus group (Section 3.3) in order to identify the main topics of interest, concerns and suggestions under each heading. Additionally, newly emerging concerns, attitude and suggestions were extracted and themed into groups according to similarity. The key themes that emerged, both from the research questions and the discussion among the participants, are further described in the results sections.

In general, all participants were intrigued by the application, and expressed their desire for a follow-up evaluation session after re-design. An overview of the results is presented in the following sub-sections, summarizing the key suggestions. Apart from the general suggestions outlined below, the sub-sections are ordered on basis of the relative importance that participants associated with them.

4.2.1. General suggestions

A suggestion given both during the focus group session and in the interview was to provide options for data exchange. Users indicated that they might want to simply share data not discussed during a virtual meeting. Hence, there was a general agreement that a dedicated space for exchange of files is needed. This could be implemented through providing a virtual workspace in the Maps and places tab, where users could upload files different from KML files. Further, one of the participants suggested providing automatic notification via e-mail to all participants in a virtual room when new maps and files are uploaded.

4.2.2. Accuracy and scale

Several participants voiced concern about accuracy. As two users noticed, when converting files to display them in the Google Earth plug-in, you lose accuracy, especially if you are working with raster satellite data on a local scale. Naturally and in the same line of thought, one of the discussed issues was regarding work with large scale maps. A major concern of the participants was regarding the inaccuracies that result from the conversion of large-scale maps to KML, especially evident when users zoom in over an area. One of the participants inquired: “What if you are working in a very small area? In this case, Google Earth is not very useful”. As a consequence, all participants agreed that there is a need to ensure optimal conversion of content from a GIS to an on-line web-based virtual globe environment.

4.2.3. Control of display and display settings

An additional suggestion in the focus group was to provide a way to control the options of the display in a virtual room. As one of the participants suggested there should be a way to “have the settings of the project…and these include study area…and then when someone logs in it just automatically zooms in to the place”. Most of the participants agreed with this point. The alternative would have led to a user navigating and trying to find anew the area of interest when another participant uploads a map in a virtual room. Automatic zoom in would also allow for resuming of work that, for some or another reason, was interrupted.

4.2.4. Effective and intuitive management of information

Participants in the focus group found the idea that the meeting will be saved in the chat window very useful. They suggested that one of the settings of the room should include setting a time-span of the history so that the user is not overwhelmed by presented information. The same need was expressed in terms of the uploaded maps in a virtual room, as users foresaw a problem with handling too much data and maps if their number increases.

4.2.5. Security and privacy

All participants agreed with the comment of one of the domain experts that “The people in a project should all have access to the same datasets and should all be able to work with them”. In contrast, the interviewee expressed his desire to be able to set the access to the datasets himself. Additionally, the interviewee suggested that the maps on display should have different access levels. The interviewee also suggested to enable users to have access to a private chat session in a virtual room, provided more team members are on-line and present at a virtual meeting.

4.2.6. Visualization and analysis operations

All participants in the focus group expressed their desire to be able to “change the colours and other user options” in an uploaded map. Additionally, the interviewee and some of the focus group participants added that they would prefer to have the option to perform at least limited analysis operations and access to attribute tables and actual values.

4.2.7. Metadata

Access to metadata, or a formal description of the data (Longely et al., 2001), are essential for the work of environmental scientists. Even though one of the main criticisms of web-based virtual globes is that they do not provide easy or adequate access to metadata (Sheppard and Cizek, 2009), only one participant brought up this issue, while the rest found it of less importance. This result was, to some extent, expected, as in the collaborative environment under development, users have the option to describe what all participants are seeing in real-time. Further, they are also provided with an option to type in and save the titles and a description for each uploaded animated map.

4.3. Usability tests

A task was considered finished if both participants in a collaborative usability session carried out the indicated activities and were able to answer the associated questions. Even though the degree of detail in responses varied, all users were able to answer the questions in the instructions they were given. The tests revealed no severe problems in terms of uploading animated maps, sending text-based chat messages, filling in names for the maps or comments, and navigating within the Google Earth plug-in display. Users were able to recollect immediately how to work with the temporal legend, invite members to a virtual room or how to download uploaded files. The test sessions, however, revealed a core of similar usability problems. The results suggest the need to address the lack of temporal synchronisation – in one of the test sessions the users ended up discussing the “dramatic changes in the study area”, but were looking at different frames of the animated maps, which resulted in confusion.

The actual use of animated maps during the collaborative test sessions was recorded and coded. However, no obvious pattern can be distinguished between group members in different groups. Most often the users either played the whole animation, or jumped to individual frames through the slider. From 12 users in total, only 2 changed the speed of the animations. The most serious problem with the animated maps in the plug-in is the lack of awareness for the actions of the users, which led to users discussing the “dramatic [temporal and spatial] changes in territory” with respect to vegetation, however they were looking at different frames of the animation.

5. Discussion

Before summarizing and discussing the final output from this study in terms of domain-expert user requirements for collaborative work with spatio-temporal data, the suitability of the selected methodology is discussed. This study utilized standard UCD methods, including questionnaire design and administration through an on-line survey, exploratory interview, focus group discussion, and usability testing. Together, these methods complement each other and contributed to a more thorough requirements elicitation. CSCW research and groupware design benefits highly from ethnographic studies, where users are observed in their natural settings prior to system design (Murray and Hewitt, 1994) or during the final evaluations (Araujo et al., 2004). Field observations allow for social and organizational dynamics to emerge, but are rarely utilized (Pinelle and Gutwin, 2000) because of the slower adoption of groupware in general. More important to our study, however, is that this type of methodology generates huge volumes of data that may be of little value if the groupware system under investigation is meant to automate relatively casual and rare events (Murray and Hewitt, 1994). Hence, it was considered inappropriate, having in mind the specific characteristics of collaborative work that were examined (presentation of research results), and the frequency of communication among the selected user group (no more than once a month). More recently, novel research within the area of CSCW (Araujo et al., 2004) and geo-collaboration (Fuhrmann and Pike, 2005) has suggested different methods and frameworks for conducting UCD for groupware. Such methodologies have not been validated by empirical data yet. Due to the exploratory nature of this research a qualitative rather than quantitative approach for data collection and analysis was undertaken. This also required a qualitative approach to ensure the trustworthiness and reliability (Bryman, 2008) of the utilized research instruments. Several strategies were adopted in order to ensure the validity and rigour of the data and the consequent analysis, recommended by Kumar (2005), Bryman (2008) and used by Wealands et al. (2007): (1) triangulation of results; (2) rich (thick) descriptions of the obtained data, and (3) peer debriefing.

In terms of results, the relatively high response rate from the online survey implied an interest in the topic. It was found that when domain expert users are concerned, basic user characteristics such as experience with computers, the web or web-based virtual globe technology are not indicative of user differences that design has to accommodate. The main differences among users were the data used during analysis, the resulting products that have to be communicated further, as well as the nature and frequency of collaboration among distributed research team members. The initial hypothesis was that (at least most of the time) the final output from analysis would be presented as data series (suitable for animation), considering that the input data are of the same nature. Results show that the products that need to be presented vary much more than expected and include spatial averages, 3D and subsurface models, but may also be non-spatial data such as text. Considering related literature (Brewer et al., 2000) such differences have not been explored in further detail. However, each of these final products would require implementing different functionality to present and facilitate collaborative work, increasing the complexity of the final interface. The synergy of a web browser and a web-based virtual globe solves a number of problems associated with geo-collaborative tools, such as the need for the users to download a separate application (Haklay, 2005). In view of the various types of data that environmental researchers use, it can accommodate a wide range of environmental data to be visualized and disseminated (Blower et al., 2007; Google, 2011). A uniform approach to design would be unsuitable, because of the varying nature and frequency of collaboration. Both frequency and type of communication depend on the purpose of collaboration (dependent versus independent work) carried out during a research project and influence the design, as well as the usability criteria that a final product has to meet. From the end-users' perspective, optimal conversion of huge files of spatio-temporal data and the accuracy of conversion would be critical for successful collaborative work.

One of the limitations of the focus group discussion was that it did not allow observation of actual distributed synchronous work with animated maps. However, the intense exchange of ideas, perceptions and experiences resulted in important insights into high-level collaborative interface issues. In addition to awareness and private work, identified user requirements related to access to a shared workspace, automatic notification for updates, and history time-span for uploaded maps. Security and privacy issues, as well as management of large amounts of information are not new groupware design challenges (e.g. Dix, 1994). These results complement the requirements related to successful collaborative work, such as low cost of data entry, efficient data transfer and interactivity for participatory GIS (Wong and Chua, 2001). A different picture emerges, however, when the brought up issues are re-examined from the perspective of geo-collaborative work with *spatio-temporal animated representations*. For instance, the interviewee brought up the need for ensuring different access levels not only to specific files, but also in terms of access to the map display. Dedicated workspace for upload of spatio-temporal data would require facilities for access to metadata that describe the temporal component as well. Additionally, specific problems that are relevant for geo-collaborative work related to scale and accuracy of conversion of different data to KML, and large file sizes were brought up. Even though not all suggestions from the interview and the focus group could be explored further, implemented and tested in detail, they allowed identifying possible barriers to collaborative work prior to implementing key functionality in the high-fidelity prototype.

Considering the results from the usability tests, all users liked the tool and agreed that it would be very useful to have in their work. They also had different suggestions for improvement, such as the addition of an audio chat. The use of a simple text-based chat in this study was preferred because of the emerging user requirements, but also because of a number of other advantages (Scholl et al., 2006). The six collaborative usability tests revealed the different usage patterns of animated maps. Difference in usage did not influence collaborative work and users were able to communicate and collaborate (allowed by spatial synchronization of the displays). However, the lack of temporal synchronization among the visual displays of users led to confusion in one of the groups. The need for effective spatial synchronization among users working with geospatial data is not new and is currently under investigation (Hardisty, 2009). Our findings, however, also further emphasize the need for temporal synchronization of the visual displays among users. Implementing an effective strategy for synchronization has to be considered carefully, having in mind that domain experts apply different strategies to view and interact with animated maps. In view of this, users should be able to view the animated maps privately without disturbing the work of their partner, especially when geo-collaborative work is carried out within a bigger group. Another important aspect that needs further investigation is the implementation of different communication tools in synergy with a collaborative animated maps interface. The participants in the final experiments felt very comfortable with the text-based chat. However, audio or video conferencing tools, as well as the addition of whiteboard sketching tools could further enhance the use of the platform. In future, animated cartographic displays could be tested with audio and/or video conferencing tools in order to determine the effect on perceptual and cognitive load when collaborative work is carried out with animated maps.

6. Conclusions

This study is an effort to contribute to a wider body of knowledge within the area of geo-collaborative information systems design. In particular, the main aim was to reveal the specific nature of user requirements when it comes to distributed geo-collaborative work with spatio-temporal data in a web-based virtual globe environment.

The generated knowledge about user requirements can provide tangible help to designers not familiar with cartographic animations and their implications for effective work in a geo-collaborative environment. Our results show that geo-collaborative work that concerns a temporal dimension may influence the complexity of the interface and functionality of a geo-collaborative tool. Apart from standard groupware (privacy) and geo-collaborative (geo-referenced comments) issues, a spatio-temporal geo-collaborative tool has to satisfy a number of additional user requirements.

In summary, when environmental domain expert users are considered, collaborative work would be mostly influenced by the variety and nature of data users use both during the analysis stage of research and when the final products need to be communicated further. The identified differences between users with respect to utilized data require: (1) optimization of on-line conversion of various types of data in KML format; (2) visualization and dissemination of location-specific non-spatial temporal data; and (3) spatial and temporal synchronization of the visual displays among geographically distributed team members. The organized focus group discussion and exploratory interview further touched upon a number of issues with respect to effective use and dissemination of spatio-temporal data. These included loss of accuracy, the need for analysis operations, and a dedicated virtual space for exchange of files (different from KML).

The emerging range of issues emphasizes the need for UCD during the development and design of geo-collaborative tools, which is all the more important when domain-expert users are concerned. The nature of work and interaction is specific for such collaborative teams and, apart from the traditional principles within HCI and CSCW, requires addressing domain-specific issues.

Taking the findings into consideration, our recommendation for further work is to elicit user requirements among the members of one or several research projects in order to identify key roles and differences in contexts of use. These could be supplemented by empirical experiments, both qualitative and quantitative, with various design alternatives to adequately address the identified user requirements.

References

Abras, C., Maloney-Krichmar, D., Preece, J., 2004. User-centered design. In: Bainbridge, W. (Ed.), Bekshire Encyclopedia of Human-computer Interaction. SAGE Publications, Thousand Oaks, USA.

Araujo, R., Santoro, F., Borges, M., 2004. A conceptual framework for designing and conducting groupware evaluations. International Journal of Computer Applications and Technology 19 (3/4), 139–150.

Baker, K., Greenberg, S., Gutwin, C., 2002. Empirical development of a heuristic evaluation methodology for shared workspace groupware. In: Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work. ACM Press, pp. 96–105.

Belani, H., Pripuzic, K., Kobas, K., 2005. Implementing web-surveys for software requirements elicitation. In: IEEE Proceedings of the Eight International Conference on Telecommunications, vol. 2, 465–469.

Blower, J., Gemmell, A., Haines, K., Kirsch, P., Cunningham, N., Fleming, A., Lowry, R., 2007. Sharing and visualizing environmental data using virtual globes. In: Proceedings of the UK e-Science All Hands Meeting, pp.102–109.

Brewer, I., MacEachren, A., Abdo, H., Gundrum, J., Otto, G., 2000. Collaborative geographic visualization: enabling shared understanding of environmental processes. In: Proceedings IEEE Information Visualization Symposium, Salt Lake City Utah, pp. 137–141.

Bryman, A., 2008. Social Research Methods. Oxford University Press, Oxford.

Cai, G., MacEachren, A., Brewer, I., McNeese, M., Sharma, R., Fuhrmann, S., 2005. Map-Mediated GeoCollaborativez crisis management. In: Proceedings IEEE 3rd Symposium on Intelligence and Security Informatics, Atlanta, GA 3495, pp. 429–435, http://www.geovista.psu.edu/publications/2005/Cai-MacEachren_LNCS3495_05.pdf.

DiBiase, D., 1990. Visualization in the earth sciences. College of Earth and Mineral Sciences, Pennsylvania State University 59 (2), 13–18.

Dix, A., 1994. Computer supported cooperative work: a framework. In: Rosenberg, D., Hutchinson, C. (Eds.), Design Issues in CSCW. Springer-Verlag, London, UK.

Fuhrmann, S., MacEachren, A., Cai, G., 2008. Geoinformation technologies to support collaborative emergency management. In: Integrated Series in Information Systems, vol. 17. Springer, USA, pp. 395–420.

Fuhrmann, S., Pike, W., 2005. User-centered design of collaborative geovisualization tools. In: Dykes, J., MacEachren, A., Kraak, M.-J. (Eds.), Exploring Geovisualization. Elsevier, pp. 591–609.

Google, 2011. KML Documentation. Retrieved December 15, 2010, from. http://code.google.com/apis/kml/documentation/.

Google Earth, 2012. Google Earth API Demo Gallery. Retrieved June 20, 2012, from. http://code.google.com/apis/earth/documentation/demogallery.html.

Gulliksen, J., Göransson, B., Boivie, I., Persson, J., Blomkvist, S., Cajander, A., 2003. Key principles for user-centered systems design. Behaviour & Information Technology 22 (6), 397–409.

Gutwin, C., Greenberg, S., 2000. The mechanics of collaboration: developing low-cost usability methods for shared workspaces. In: Proceedings 9th IEEE International Workshops on Enabling Technologies. Infrastructure for Collaborative Enterprises, Gaithersburg, MD, pp. 98–103.

Haklay, M., 2005. Usability dimensions of collaborative GIS. In: Dragicevic, S., Balram, S. (Eds.), Collaborative Geographic Information Systems. Idea Group Publishing, New York.

Haklay, M., 2010. Computer-mediated communication, collaboration and groupware. In: Haklay, M. (Ed.), Interacting with Geospatial Technologies. Wiley-Blackwell, London, UK.

Haklay, M., Nivala, A.-M., 2010. User-centred design. In: Haklay, M. (Ed.), Interacting with Geospatial Technologies. Wiley-Blackwell, London, UK.

Haklay, M., Skarlatidou, A., Tobón, C., 2010. Usability engineering. In: Haklay, M. (Ed.), teracting with Geospatial Technologies. Wiley-Blackwell, London, UK.

Hardisty, F., 2009. GeoJabber: enabling geo-collaborative visual analysis. Cartography and Geographic Information Science 36 (3), 267–280.

Harrower, M., 2003. Tips for designing effective animated maps. Cartographic Perspectives 44, 63–68.

Harrower, M., MacEachren, A., Griffin, A., 2000. Developing a geographic visualization tool to support earth science learning. Cartography and Geographic Information Science 27 (4), 279–293.

Haynes, S., Purao, S., Skattebo, A., 2009. Scenario-based method for evaluation of collaborative systems. Computer Supported Cooperative Work 18 (4), 331–356.

Jakobsson, A., 2003. User Requirements for Mobile Topographic Maps. Report of the GiMoDig Project, Deliverable D2.1.1. Finish Geodetic Institute, Finland, p. 93.

Keßler, C., Rinner, C., Raubal, M., 2005. An argumentation map prototype to support decision-making in spatial planning. In: Toppen, F., Painho, M. (Eds), Proceedings of Eighth Conference on Geographic Information Science (AGILE), Estoril, Portugal, pp. 135–142.

Köbben, B., Graham, M., 2009. Maps and mash-ups: the Nsational Atlas and Google Earth in a geodata infrastructure. In: 12th AGILE International Conference on Geographic Information Science. Germany, Hannover.

Koua, E., MacEachren, A., Turton, I., Pezanowski, S., Tomaszewski, B., Frazier, T., 2009. Conceptualizing a user-support task structure for geocollaborative disaster management environments. Advances in Management Information Systems 16, 254–278.

Kumar, R., 2005. Research Methodology, third ed. SAGE Publications, Thousand Oaks, USA.

Longley, P., Goodchild, M., Maguire, D., Rhind, D., 2001. Geographic Information Systems and Science. John Wiley and Sons, Chichester, UK.

MacEachren, A., 2001. Cartography and GIS: extending collaborative tools to support virtual teams. Progress in Human Geography 25 (3), 431–444.

MacEachren, A., 2005. Moving geovisualization toward support for group work. In: Dykes, J., MacEachren, A., Kraak, M.-J. (Eds.), Exploring Geovisualization. Elsevier, Amsterdam, pp. 445–461.

MacEachren, A., Cai, G., 2006. Supporting group work in crisis management: visually mediated human-GIS-human dialogue. Environment and Planning B: Planning and Design 33, 435–456.

Maguire, M., 1998. RESPECT: User-Centred Requirements Handbook. Project TE 2010 RESPECT, Deliverable D5.3. In: EC Telematics Applications Programme. HUSAT Research Institute, UK.

Mayhew, D., 1999. The Usability Engineering Lifecycle. Morgan Kaufmann, San Francisco, CA.

Morgan, D., 1988. Focus Groups as Qualitative Research. SAGE Publications, Newbury Park, CA.

Morgan, D., 1998. The Focus Group Guidebook, first ed. SAGE Publications, Thousand Oaks, CA.

Murray, D., Hewitt, B., 1994. Capturing interactions: requirements for CSCW. In: Rosenberg, D., Hutchinson, C. (Eds.), Design Issues in CSCW. Springer-Verlag, London, UK.

Nielsen, J., 1993. Usability Engineering, first ed. Academic Press, London, UK, p. 362.

Peterson, M., 1995. Interactive and Animated Cartography. Prentice Hall, Engelwood Cliffs.

Pinelle, D., Gutwin, C., 2000. A review of groupware evaluations. In: Proceedings of the Ninth IEEE WETICE 2000 Workshop on Enabling Technologies: Infrastructure for collaborative enterprises, Gaithersburg, ML, USA.

Rinner, C., 2001. Argumentation maps: GIS-based discussion support for online planning. Environment and Planning B – Planning and Design 28 (6), 847–863.

Scholl, J., McCarthy, J., Harr, R., 2006. A comparison of a chat and audio in media rich environments. In: Proceedings of the ACM Conference on Computer Supported Cooperative Work. IEEE, pp. 323–332.

Sheppard, S., Cizek, P., 2009. The ethics of Google Earth: crossing thresholds from spatial data to landscape visualization. Journal of Environmental Management 90 (6), 2102–2117.

Sidlar, C., Rinner, C., 2006. Analyzing the usability of an argumentation map as a participatory spatial decision support tool. Urban and Regional Information Systems Association (URISA) Journal 19 (1), 47–55.
Sidlar, C., Rinner, C., 2009. Utility assessment of a map-based online geo-collaboration tool. Journal of Environmental Management 90 (6), 2020–2026.
Stiemerling, O., Cremers, A., 1998. The use of cooperation scenarios in the design and evaluation of a CSWC system. IEEE Transactions on Software Engineering 24 (12), 1171–1181.
van Elzakker, C.P.J.M., Wealands, K., 2007. Use and users of multimedia cartography. In: Cartwright, W., Peterson, M., Gartner, G. (Eds.), Multimedia Cartography. Springer, Berlin, pp. 487–504.
Van Helvert, J., Fowler, C., 2003. Scenario Based User Needs Analysis. Chimera Working Paper 2003-02, Colchester. University of Essex, UK.
Virranteus, K., Fairbrian, D., Kraak, M.-J., 2009. ICA research agenda on Cartography and GI Science. The Cartographic Journal 46 (2), 63–75.
Wealands, K., Miller, S., Benda, P., Cartwright, W., 2007. User assessment as input for useful geospatial representations within mobile Location-Based Services. Transactions in GIS 11 (2), 283–309.
Weber, R., 1990. Basic Content Analysis. Sage Publications, Newbery Park, CA.
Wong, S., Chua, Y., 2001. Data intermediation and beyond: issues for web-based PPGIS. Cartographica 38 (3–4), 63–80.