ParcitipatoryGIS.com: A WebGIS-based Collaborative Multicriteria Decision Analysis

Soheil Boroushaki *
Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2, Canada
E-mail: sboroush@uwo.ca
Fax: (519) 661-3750

Jacek Malczewski
Department of Geography, University of Western Ontario, London, Ontario, N6A 5C2, Canada
E-mail: jmalczew@uwo.ca
Fax: (519) 661-3750

Abstract This paper presents a framework for a collaborative WebGIS-Multicriteria Decision Analysis. It focuses on the underlying concepts, theories and techniques for designing and implementing the conceptual framework. The framework, called *ParticipatoryGIS.com*, has been implemented in the Google Maps environment. It consists of two main elements supporting the deliberative and analytic components of decision-making process. The deliberative part is based on the concept of argumentation maps. The analytic component consists of multicriteria decision analysis methods. *ParticipatoryGIS.com* uses the server-side architecture approach to Web-based GIS. It employs HTML, CSS and JavaScript on the client-side and a combination of PHP scripting language and a MySQL database on the *ParticipatoryGIS.com* server. The Google Maps server provides the map and Google Maps API.

Keywords
GIS; Multicriteria evaluation; Spatial decision-making; Fuzzy majority; Ordered Weighted Averaging; Linguistic quantifiers

* Corresponding author

1. Introduction

Spatial decision-making has traditionally been a ‘closed’ process with a limited opportunity for the general public to participate. Many spatial decisions in the public sector have been made by planners and politicians within an environment that the public has no direct access, while it has been claimed that those decisions reflect the public opinion. However, the rapid changing of the planning context, new interest groups’ demands and needs, and the recent developments in information and communication technology have called for more effective solutions to spatial decision-making problems involving public collaboration and participation (Jankowski et al., 1997; Carver and Peekham, 1999; Jankowski and Nyerges, 2001; Dragićević, 2004).

The adequacy of spatial planning has often been questioned regarding the lack of representation from some interest groups (the equity problem) and the incapability for active participation (the access problem) due to its closed, synchronous and place-based nature. To address the problems of equity and access the process of spatial planning requires collaboration and distribution over an extended period of time (Carver and Peekham, 1999; Jankowski and Nyerges, 2001; Dragićević and Balram, 2004).

While the planners and decision-makers have full access to relevant spatial data / information and spatial planning tools such as Geographic Information Systems (GIS) and related technologies, there are relatively few spatial planning and decision-making tools available to the general public. This division has been one of the main criticisms of GIS (Pickles, 1995; Carver, 1999; Carver and Peekham, 1999; Dragićević, 2004). GIS has been typically a centralized, exclusionary, expensive and technocratic technology that needs expert users for effective and efficient operations (Dragićević, 2004; Miller, 2006).

GIS has been criticized as being an elitist technology that widens the gap between expert users and the public when used for planning and decision-making applications (Pickles, 1995). The main challenges of GIS-based spatial decision-making applications lie in bridging this gap by providing a tool for enhancing public participation and addressing the issues of access and equity. Implementing GIS within the World Wide Web environment and integrating its capabilities with multicriteria decision analysis (MCDA) methods can provide a mechanism for bridging the gap between the experts and the public (Carver, 1999; Malczewski, 2006a; Dragićević and Balram, 2004).

Web-based GIS (WebGIS) responds to the criticism of GIS by offering solutions that are accessible to non-experts. Moreover, online tools such as discussion forums provide an alternative to the traditional place-based planning (for example, the public meetings and open houses) in that they do not require in-person attendance. By operating on the Internet, access to GIS is not restricted by time or location (Carver, 1999, Jankowski and Nyerges, 2001; Dragićević, 2004, Dragićević and Balram, 2004).

In addition, the integration of GIS and MCDA facilitates the participation in spatial decision-making by allowing participants to explore different aspects of a decision problem and express their preferences (Carver, 1999; Malczewski, 2006a). MCDA provides a mechanism for expressing the preferences and objectives of the participants and generating a compromise solution which includes the participants' evaluations. MCDA can offer a structured environment for investigating the intensity and sources of conflicts among different participants and improve communication and understanding among multiple decision-makers which in turn pave the way for converging preferences and building a consensus in such a way that a minimum conflict solution can be generated (Feick and Hall, 1999; Jankowski and Nyerges, 2001; Malczewski, 2006a, 2006b). Within this setting, the ultimate goal of the GIS-based multicriteria decision analysis (GIS-MCDA) procedures is to tackle two distinct aspects of spatial collaborative decision-making and planning. The procedures attempt to address: (i) the deliberative structure of spatial planning; by building a consensus among various decision-makers and interest groups through organizing and facilitating communication, and (ii) the analytical structure of spatial decision-making; by generating a compromise solution that best represents the preferences of all participants (Malczewski, 1996; Feick and Hall, 1999, 2004; Malczewski, 2006b; Jankowski and Nyerges, 2001; Simão et. al., 2008).

Since mid 1990's, many research efforts have been focused on integrating GIS capabilities and MCDA methods in the context of the Internet (Menegolo and Peckham, 1996; Barghava and Tettlbach, 1997; Wan et. al., 1999; Zhu and Dale, 2001; Zhu et. al., 2001; Rinner and Malczewski, 2002; Dragićević and Balram, 2004; Evans et. al., 2004; Hall and Leahy, 2006; Karnatak et. al., 2007; Rao et. al., 2007; Simão et. al., 2008). Rinner and Malczewski (2002) concluded that most of the first generation (1996-2001) WebGIS –MCDA applications focused on the technical aspects of GIS and MCDA integration to address the analytical structure of spatial problems. Many of those systems do not assist users in choosing between decision alternatives but instead they provide decision support by facilitating information access and visualizing. In addition, most available systems are custom-built for specific applications or data and there are no generic prototypes that can accept user-defined data and information online.

Most of the second generation WebGIS-MCDA applications addressed the shortcomings of the analytical structure by providing more comprehensive and sophisticated analytical modules (Rinner and Malczewski, 2002). However, technological and methodological deficiency can still be noted in those systems in contrast with the nature of the collaborative spatial planning and decision-making. First and for most, the majority of the recent advanced WebGIS-MCDA systems, like their first generation counterparts, are not responsive to the deliberative dimension of spatial decision-making. Specifically, they lack a mechanism or capability to support discussion (for example, Rinner and Malczewski, 2002; Evans et. al., 2004; Karnatak et. al., 2007; Rao et. al., 2007).

Moreover, many of the recent applications are developed based on commercial Web-based GIS packages, such as ArcIMS (for example, Dragićević and Balram, 2004; Karnatak et. al., 2007; Rao et. al., 2007; Simão et. al., 2008). Miller (2006) has questioned the degree to which a GIS can play a role of a participatory system if it is built based on expensive commercial software unavailable to most of the communities and interest groups. Accordingly, it is important to develop a collaborative WebGIS application based on an Open Source or free-to-use software (with no monetary cost for acquisition or licensing) using publicly available free geospatial data. This would address the objective of collaborative GIS regarding communities' limitations. In this case, the only constraint on developers and users of such systems should be the limits of their willingness to participate, explore and learn from these systems but not their financial capabilities (Hall and Leahy, 2006).

The launch of Google Maps service in 2005 brought countless opportunities for communities around the world to have free access to easy-to-use and browser-based WebGIS functionalities as well as high quality geospatial data. Google Maps and the applications being built using its easy-to-use Application Programming Interface (API) provide a free WebGIS for the general public and non-GIS experts where they can interact with and present their customized information in a user friendly and familiar environment. In contrast, although other Open Source Web-based GIS systems such as University of Minnesota MapServer (MapServer, 2008) are available for free, they require GIS experts with the knowledge of digital mapping, encoding and transfer protocol due to the complex process of their customization (Miller, 2006; Rinner et. al., 2008). This makes Google Maps an excellent candidate to make the base of any collaborative WebGIS development.

The main objective of this paper is to present a Google Maps-based WebGIS framework and its implementation for collaborative multicriteria spatial decision-making. The proposed framework is enabled to address simultaneously deliberative and analytic dimensions of spatial decision-making and planning in an integrated and cohesive fashion. The remainder of this paper is organized as follows. Section 2 provides detailed background information. We first examine the synergetic capabilities of the integration of GIS and MCDA to tackle spatial planning problems; then we discuss the potentials of the Internet as a medium to facilitates asynchronous and distributed collaborative spatial decision-makings, and finally we review ArgooMap prototype's properties as a tool for spatially referenced communications which corresponds to the deliberative element of spatial planning and decision-making. These segments are brought together in Section 3 which describes our conceptual framework for collaborative spatial multicriteria decision-making. Section 4 explains system architecture and user interface design for the framework implementation. The final section presents concluding remarks.

2. Background

2.1 GIS-based Multicriteria Decision Analysis

Spatial multicriteria decision-making problems typically involve a large set of decision alternatives that are evaluated on the basis of multiple, conflicting and incommensurate evaluation criteria. The alternatives are usually evaluated by a number of individuals (e.g., planners, stakeholders, interest groups). The individuals are characterized by unique preferences (value judgments) with respect to the relative importance of the criteria on the basis of which the alternatives are evaluated (Malczewski, 1999).

GIS-based multicriteria decision analysis (GIS-MCDA) can be defined as a process that transforms and combines geographical data (map criteria) and value judgments (decision-makers' preferences) to obtain relevant information for decision-making. The main rationale behind integrating GIS and MCDA is that these two distinct areas of research can complement each other. While GIS is commonly recognized as a powerful and integrated tool with unique capabilities for storing, manipulating, analyzing and visualizing spatial data for decision-making, MCDA provides a rich collection of procedures and algorithms for structuring decision problems, designing, evaluating and prioritizing alternative decisions. It is in the context of synergetic capabilities of GIS and MCDA that one can see the benefits for advancing theoretical and applied researches on the integration of GIS and MCDA (Malczewski, 1999, 2006a).

The effort to integrate GIS and MCDA can be associated with the current proliferation stage of GIS development (Malczewski, 2006a). During this phase, the systems have been evolving from a 'close' or expert-oriented to an 'open' user-oriented technology. This has stimulated a movement in the GIS community towards using this technology to increase the democratization of the decision-making process via public participation and collaboration. Malczewski (2006a) suggested that it is in the context of the debate on the interrelationship between "GIS and society" (Pickles, 1995) that one can see the potential for constructing GIS-MCDA systems to enhance and facilitate collaborative decision-making.

In a collaborative multicriteria decision-making setting, GIS-MCDA takes the format of aggregating individual judgments into a group preference in such a way that the best compromise alternative can be identified (Malczewski, 2006 a, 2006b). Accordingly, a collaborative decision analysis involves a two-stage procedure: (i) the MCDA decision rules (the decision rules for combining the criterion maps according to the individual decision-maker's preferences), and (ii) the collective choice rules (the decision rules for aggregating individual preferences into a group preference).

It has been argued that GIS-MCDA systems can potentially enhance collaborative decision-making process by providing a flexible problem-solving framework where participants can explore, understand and redefine a decision problem (Feick and Hall, 1999; Jankowski and Nyerges, 2001; Kyem, 2004, Malczewski, 2006a, 2006b). MCDA approaches can integrate multiple views of decision problems. They improve communication and facilitate the process of building a consensus and reaching compromise solutions. GIS-MCDA can support the collaborative process by providing a tool for structuring decision problems and facilitating communication among decision-makers (Malczewski, 2006 a, 2006b).

2.2. Web-based GIS-MCDA

The World-Wide Web or more practically the Internet (as a deployment and communication medium) has introduced new trends in the mapping and the democratization of spatial data and maps. Using Internet, GIS can make its concept more 'open', accessible and mobile to everyone, therefore facilitating notions such as democratization of spatial data (and in turn spatial decision-making), open accessibility and an effective distribution of spatial information. In this setting, the public access to the planning process is enhanced and the technology contributes to greater participation in democratic processes (Carver, 1999; Carver and Peekham, 1999; Dragićević, 2004, Dragićević and Balram 2004; Miller, 2006).

A WebGIS framework can generate a distributed and collaborative environment with continual time setting for mapping and decision-making. Integrating MCDA methods into WebGIS (WebGIS-MCDA) can provide an interactive Web-based tool for users to explore digital maps and express their opinions about spatial decision problems. In addition, individuals uncomfortable with expressing their views in public can voice their opinions and preferences in a detached environment and consequently a wider and more representative audience can be reached. WebGIS-MCDA systems have the potential to stimulate a 'bottom-up' approach to spatial decision-making by providing public access to the data and models. This framework allows participants in a decision-making process to input their value judgments based on "different location-different time" dimensions of the spatial-temporal dimensionality of collaborative decision-making (Jankowski et. al., 1997). Consequently, the equity and access problems of the traditional decision-making process can be addressed. The equity issue is handled by a Web-wide distributed system design and the access problem can be addressed by imbedding a collaborative mechanism within the structure of WebGIS (Carver, 1999, Jankowski and Nyerges, 2001; Dragićević, 2004, Dragićević and Balram, 2004; Malczewski, 2006b).

2.3 ArgooMap: A 'Google Map'-based tool for spatially referenced communication

The Argumentation Map (ArguMap) concept was proposed by Rinner (1999, 2001) to support geographically referenced discussions in GIS by providing visual access to public geo-referenced debates in the planning domain. ArguMaps are based on the combination of an online discussion forum and a Web-based GIS. They were developed as a method for structuring debates with spatial elements in asynchronous online discussions (Rinner, 2001; Sidlar and Rinner, 2007).

Keßler (2004) implemented an Argumentation Map prototype as proof-of-concept using open-source software to fulfill the requirements for the ArguMap concept and to minimize the development cost. This prototype of an Argumentation Map as a WebGIS was implemented using: Geo Tools Lite mapping tool kit, a custom-built Java applet for a discussion forum, the MySQL database for storing users' geographically referenced discussions and the University of Minnesota MapServer providing background map layers (Keßler, 2004; Sidlar and Rinner, 2007).

ArguMap prototype has been used for tackling a number of spatial planning problems (e.g., Sidlar and Rinner, 2007; Simão et. al., 2008). However, there are some technological difficulties with using the ArguMap prototype. The main shortcoming of the prototype is due to its implementation as a Java Applet that requires Java Virtual Machine to be downloaded first and set up on users' machines, which, in turn, diminishes the efficiency of the system. In addition, the complex procedure of customizing MapServer and Geo Tools Lite to create a WebGIS makes the development process difficult. These problems led Rinner et. al. (2008) to develop ArgooMap — an implementation of the Argumentation Map concept using the Google Maps API. The main objective of the migration from Java Applet platform to Google Maps-based argumentation was to improve the usability of prototype and in the meantime cut the development cost by using free-of-charge geospatial data and functionalities provided by Google Maps service. The ease of use is crucial for the success of such systems where the target group is the general public with no familiarity with GIS functionalities (Rinner et. al., 2008).

3. Conceptual framework for a collaborative WebGIS-MCDA

It has been argued that GIS-MCDA methods provide a framework which can handle different views and debates on the identification of elements of a complex decision problem, organize the elements into a hierarchical structure, explore the relationships among components of the problem and stimulate communication among participants (Malczewski, 2006 a, 2006b). However, GIS-MCDA approaches have traditionally focused on the integration of GIS systems (desktop or Web-based) and MCDA algorithms which address the analytical aspect of such systems. On the other hand, although Argumentation Maps can visualize the alternative locations and the geo-referenced discussions on different aspects of spatial decision-making problem, they lack the evaluation capabilities for finding the compromise alternative. To this end, we suggest that the implementation of Argumentation Maps concept within a WebGIS-

MCDA would result in a spatial decision-making prototype capable of simultaneously addressing deliberative and analytical dimensions of spatial decision-making in an asynchronous and distributed environment.

Fig. 1 illustrates the proposed conceptual framework for constructing a collaborative WebGIS-MCDA, which we called ‘ParticipatoryGIS.com’ or for short ‘ParticipatoryGIS’. It consists of two main elements of deliberation and analysis, both implemented within Google Maps environment, which provides required geospatial data and GIS functionalities. The analytical part of the framework corresponds to the collaborative MCDA decision rule by employing an MCDA algorithm for individual decision-making and a collective choice rule to generate the group solution (see Section 2.1). In ‘ParticipatoryGIS’ we utilized quantifier-guided Ordered Weighted Averaging (OWA) (Yager, 1997) and the fuzzy majority approach (Passi and Yager, 2006) for MCDA decision rule and collective choice rule, respectively. Finally, the conceptual framework includes the aggregation of ArgooMap representing the deliberative element of the framework with the collaborative MCDA decision rule, which yields in a Web-based prototype competent to tackle both dimensions of spatial decision-making and planning.

4. Implementing the framework

4.1. System architecture

‘ParticipatoryGIS’ uses the server-side architecture approach (Rinner and Jankowski, 2002) to Web-based GIS. It employs HTML, CSS and JavaScript on the client-side and a combination of PHP scripting language and a MySQL database on the ‘ParticipatoryGIS’ server. In addition, Google Maps server provides the map and Google Maps API, upon which the system has been built and the users are mostly rely on their functionalities (Fig. 2).

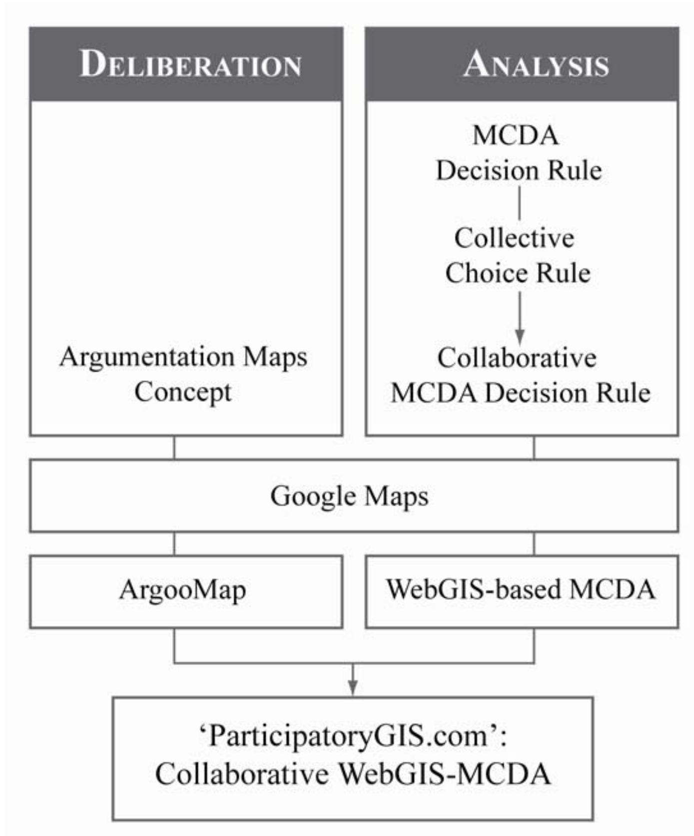

Fig. 1. Conceptual framework for collaborative WebGIS-MCDA.

All the geographical data (e.g., coordinates) and also alphanumeric information used by both deliberative and analytical elements of the system are stored in a MySQL database on 'ParticipatoryGIS' server. The data and information required for the analytical component consist of: (i) user registration information (this information is required for the deliberative part for user identification), (ii) decision alternatives' locations (coordinates and addresses), (iii) evaluation criteria values for each alternative, (iv) criteria importances (weights) according to each user's preferences; (v) the final score and rank of each alternative according to each individual judgment and (vi) the score and rank of each alternative based on the majority of the participants representing the group preference. From the deliberative part, markers, discussion contributions and the relationship between them are also stored in the database.

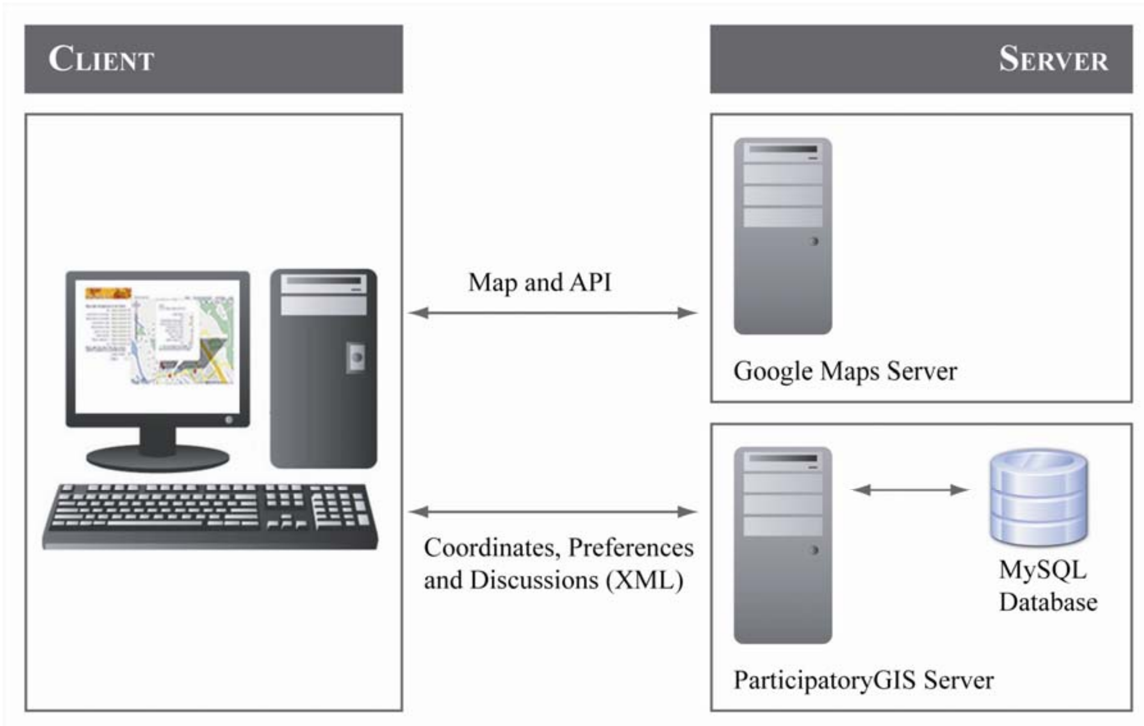

Fig. 2. System architecture of ParticipatoryGIS.com.

The system architecture, for most of the client-server communications, utilizes JavaScript as the client-side programming script and XML as the preferred format for data transfer. This combination also known as AJAX enables the Web implementations to have continuous and seamless interaction with the server without waiting for the whole Web page to be reloaded. AJAX technology enables us to implement the integration of analytical and deliberative parts (elements of the conceptual framework) in a single Web page with a set of tools and functionalities resembling a desktop GIS. In the next section we discus the implementation of the user interface of 'ParticipatoryGIS'.

4.2. User interface description

Fig. 3 shows the workflow of ‘ParticipatoryGIS’. The workflow consists of three main sections: (i) registration and log in, (ii) main map, and (iii) questionnaire. Registration and log in section has consisted of four pages: (i) log in, (ii) user registration, (iii) terms and conditions, and (iv) about ‘ParticipatoryGIS’. Users accessing the Website for the first time can register on the ‘user registration’ page. By completing the registration, users are then redirected to the ‘tutorial’ page. Upon registration, users have to read and aggress to the terms of the ‘ParticipatoryGIS’ use, which are available on the ‘terms and conditions’ page. Returning users can log into the system using the ‘log in’ index page on which they are redirected to the ‘main decision map’. The ‘about ParticipatoryGIS’ page introduces the design and development team.

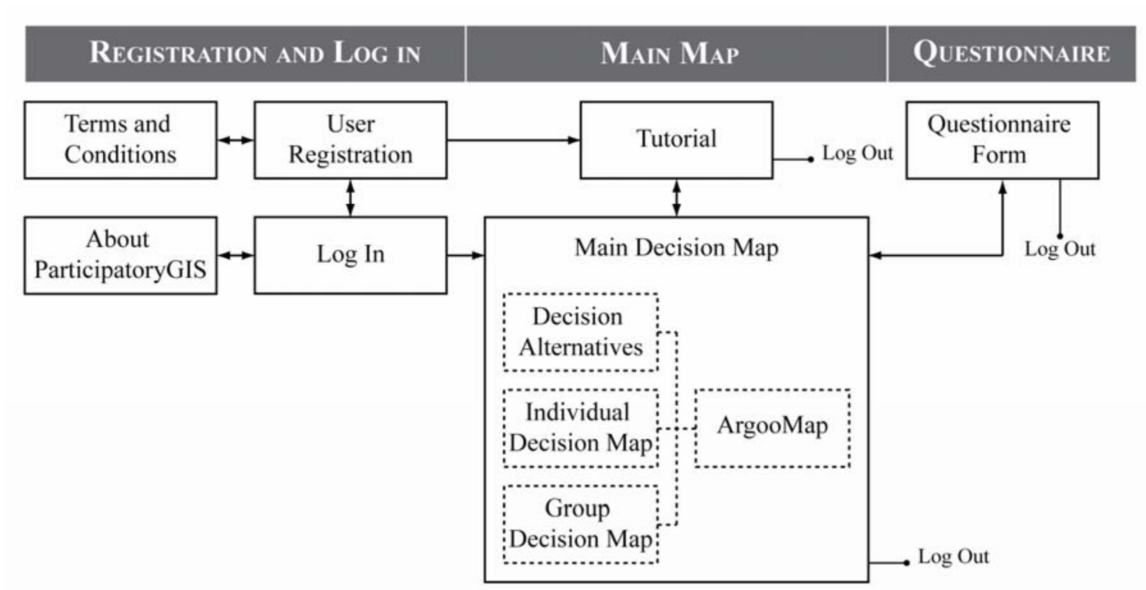

Fig. 3. Sections and workflow of ParticipatoryGIS website.

The main map section of the system has been constructed using two Web pages: ‘tutorial’ and ‘main decision map’. ‘Tutorial’ describes the goal and objectives of the spatial decision problem at hand and provides a detailed explanation of the properties and geospatial characteristics of the decision alternatives. The definitions evaluation criteria and their units of measurement are given in the ‘tutorial’ page as well. In addition, it provides a step by step walkthrough on how to use the Website for selecting the preferred location and how to participate in the debates and communication with other users through implemented ArgooMap. Within the ‘main decision map’ component, four map layers can be turned on and off using AJAX technology. The map layers are as follows: decision alternatives map, individual decision map and group decision map from analytical element and ArgooMap.

Decision alternatives map shows the locations of the decision alternatives. By clicking on each alternative a window will open and displays the corresponding properties and evaluation criteria values. This enables the users to browse and compare the characteristics of the alternatives (Fig. 4). The users can then input their preferences regarding the relative importance of each criterion using a set of linguistic terms. The set of six linguistic terms used in ‘ParticipatoryGIS’ include: none, very low, low, medium, high and very high (see Chen and Hwang, 1992). In addition, users should choose a linguistic label to define how many of the evaluation criteria ought to be satisfied by an acceptable location. Then, the linguistic label guides the OWA aggregation procedure which generates the final score for each alternative. By submitting the user’s preferences, individual decision map visualizes the rank of each alternative based on its OWA score (Fig. 5).

Within the ‘main decision map’ element, users can switch on ‘group decision map’. The ‘group decision map’ shows the rank order for each alternative based on the majority preferences of the users (Fig. 6). The alternatives’ scores in the group decision map layer are generated by the fuzzy majority procedure (see Passi and Yager, 2006). In addition, the users can turn on or off Argoomap as an overlay in conjunction with the analytical maps (Fig. 7). By saving the preferences, users are then redirected to the questionnaire form. The questionnaire facilitates the evaluation of the different aspects of the characteristics of users who participants in the process of decision-making and pave the way for further studies on the usability analysis of the prototype.

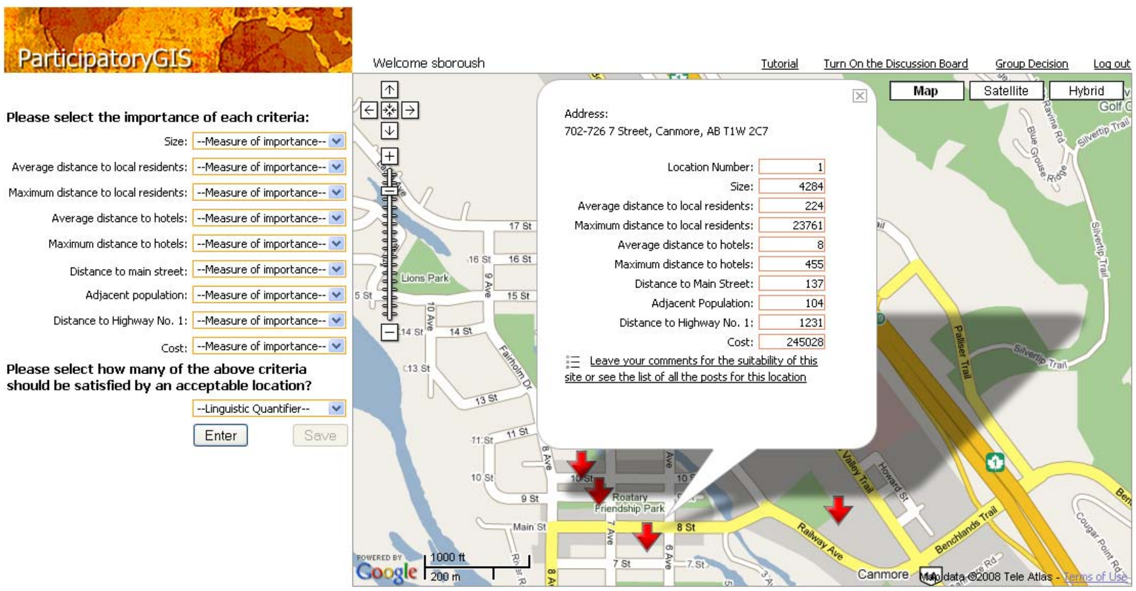

Fig. 4. Decision alternatives map layer of the main map page (Screenshot from ParticipatoryGIS case study, Canmore, Alberta).

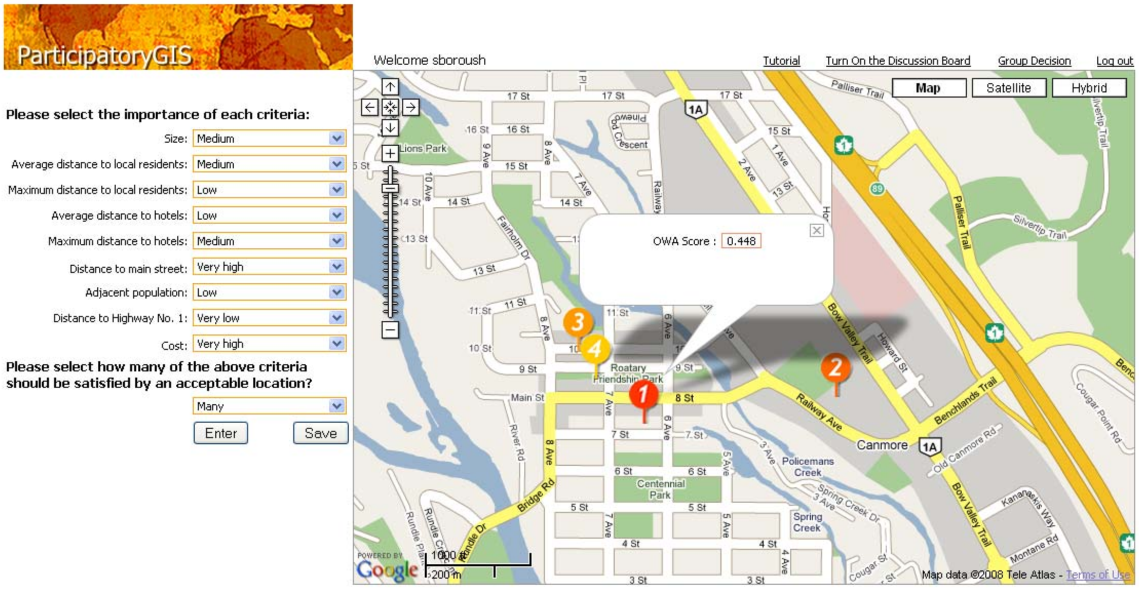

Fig. 5. Individual decision map layer (Screenshot from ParticipatoryGIS case study, Canmore, Alberta).

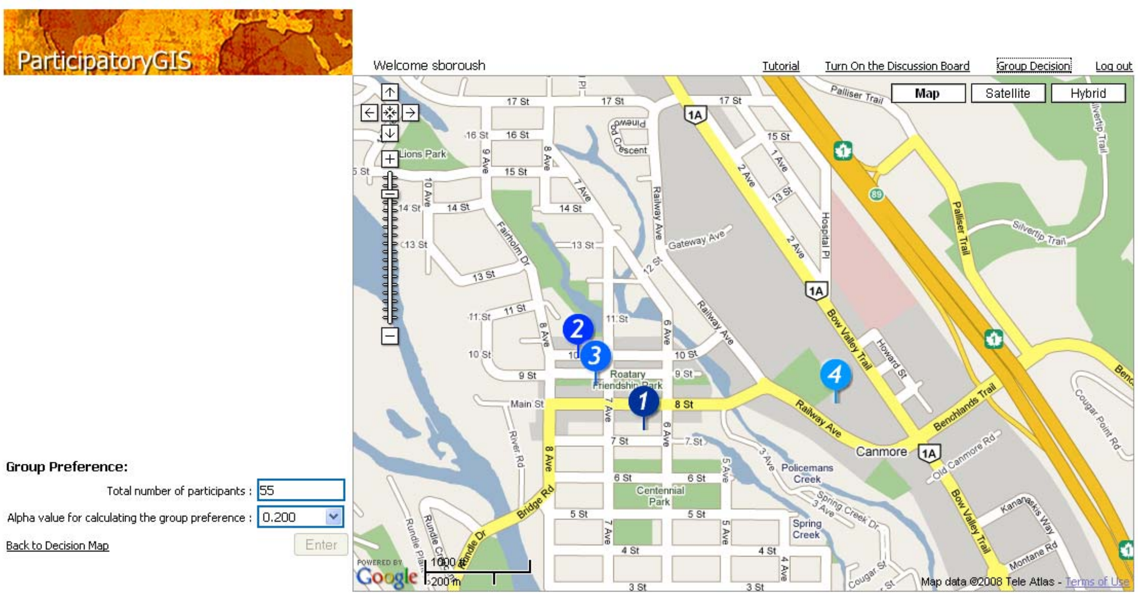

Fig. 6. Group decision map layer (Screenshot from ParticipatoryGIS case study, Canmore, Alberta).

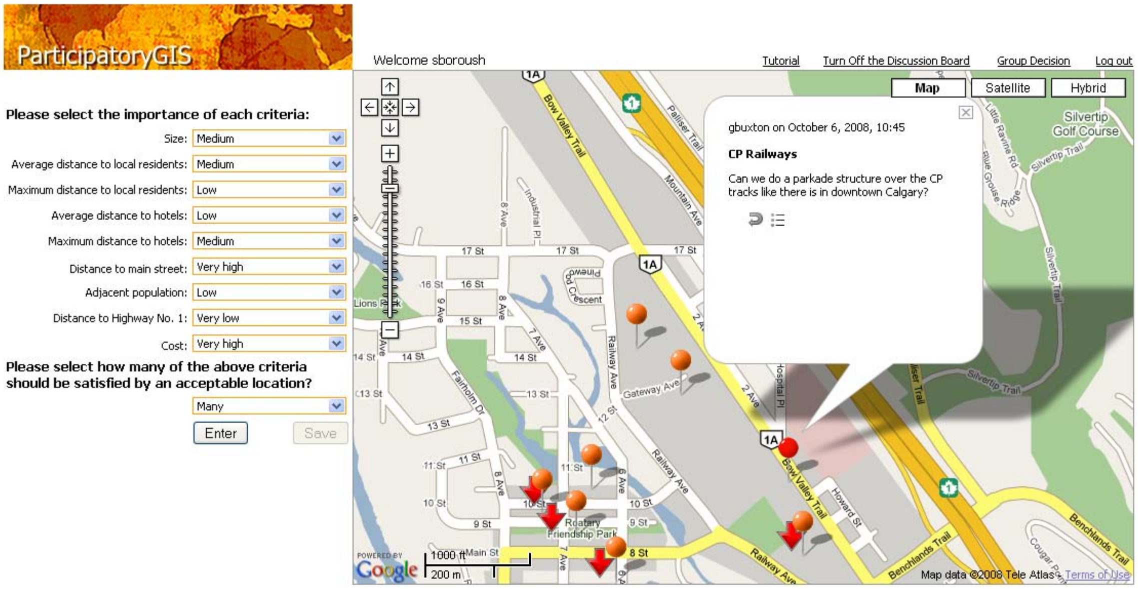

Fig. 7. Decision alternatives map layer and ArgooMap overlay within main decision map (Screenshot from ParticipatoryGIS case study, Canmore, Alberta).

5. Conclusion

The purpose of this paper was to describe the design of a novel conceptual framework for a Web-based collaborative spatial decision-making and its implementation in ‘ParticipatorGIS’ as a proof-of-concept. The framework integrates two prominent components of spatial decision-making and planning, deliberation and analysis, in a cohesive fashion. The deliberative element of the prototype facilitates and encourages the communication and debate among the decision-makers and stakeholders, while the analytical structure provides procedures for generating a compromise solution.

We proposed to build the prototype using Google Maps service to gain access to the free-of-charge geospatial data and user friendly environment. For the implementation of the framework, we used free scripting language, database and map service which enhances the sustainability of the collaborative spatial decision-making projects. The architecture of the prototype have been selected and implemented in a way that makes it a straightforward process to customize the system for different spatial decision problems. Although, 'ParticipatoryGIS' has been designed and implemented for the spatial multicriteria problems with predefined alternatives, the same prototype can be use through ArgooMap for scenarios in which the alternatives are generated through public participation.

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