Integrating Spatial Data and Decision Models in a E-Planning Tool

Pedro Antunes,[1] Claudio Sapateiro,[1] Gustavo Zurita,[2] and Nelson Baloian [3]

[1] University of Lisbon, Faculty of Sciences,
Campo Grande, Lisbon, Portugal
paa@di.fc.ul.pt, claudio.sapateiro@estsetubal.ips.pt
[2] Universidad de Chile, Economy and Business School,
Diagonal Paraguay 257, Santiago de Chile, Chile
gzurita@ing.puc.cl
[3] Universidad de Chile, Engineering School,
Blanco Encalada 2120, Santiago de Chile, Chile
nbaloian@gmail.com

Abstract. We review several decision models to derive six fundamental requirements to collaborative spatial decision-making: perceiving changes in spatial data; retaining interpretation mindsets; externalizing actions and expectancies in spatial data; organizing divergent and convergent working modes; supporting the recognition of situation-action elements; and managing task/pattern structures. A review of the current state of the art shows limited support to some of these requirements, in particular task/pattern and divergent/convergent support. An e-planning prototype was developed to demonstrate the impact of these requirements in collaborative spatial decision-making. Results from a preliminary experiment indicate the prototype enables people to contribute, explain, exteriorize and share their ideas in relation with spatial references.

Key words: Geocollaboration, Decision Models, e-Planning

1. Introduction

This research was motivated by the design of a collaborative tool supporting e-planning. E-planning is the label adopted by a broad research agenda addressing the interaction between information technology and planning, including various key concerns such as territorial management, policy making, governance, citizenship and participation [1].

The main vision driving the tool design was supplying various stakeholders – architects, urban designers, city planners and public administrators – with a collaborative tool capable to advance new perceptions and ideas regarding city planning. City planning is a complex process challenging design with a variety of technical and human requirements. In our view, the best approach to a wicked situation like this one is starting

Antunes , P., C. Sapateiro, G. Zurita and N. Baloian (2010) Integrating Spatial Data and Decision Models in a E-Planning Tool. Groupware: Design, Implementation, and Use. 16th CRIWG Conference on Collaboration and Technology, Maastricht, The Netherlands, vol. 6257, pp. 97-112. Heidelberg, Springer-Verlag.

highly focused on a very specific challenge and only moving forward when that challenge is sufficiently understood and conveniently resolved.

In our case study, the main challenge is integrating spatial data with the decision model. City planning involves various types of geographically related data. This data is traditionally managed with Geographical Information Systems (GIS).

The integration of spatial data with decision models is not new. Actually, it has lead to an emerging category of GIS designated Collaborative Spatial Decision Making (CSDM) [2, 3]. CSDM may also be regarded as a combination of GIS with Decision Support Systems (DSS) and Group Support Systems (GSS) [4, 5], although falling outside the typical DSS/GSS categorization [6]. According to the state of the art, CSDM concerns the provision of the following functionality [7]: collecting spatially-related data, identifying locations according to a set of criteria, exploring relationships, displaying and analyzing data, and exporting data to other systems and tools.

While this functionality is essential to integrate spatial data with decision-making activities, it does not address some specific problems: (1) it does not explicitly consider models of the decision-making process, which means its potential users will have to informally manage the process; (2) in complex contexts, decisions are highly dependent on collaboration, which requires adding support to coordination, awareness and collaborative visualization into the CSDM functionality; and finally, (3) decision making also brings new types of spatially-related data, such as talks, discussions, negotiations, and brainstorms, which should be seamlessly integrated with the remaining data.

We may express with more accuracy that our main challenge is modeling spatial data within the context of a broader model of the decision-making process, understood as a collaborative endeavor. The paper is organized as follows. We start with a review of several decision-making models to highlight the main model constructs that inform CSDM design. We then review several CSDM tools to highlight present omissions and opportunities. In Section four we describe the e-planning tool developed to explore the integration between spatial data and decision models. In section five we discuss the tool's evaluation. We conclude the paper with a synthesis and discussion of the obtained results.

2. Overview of Decision-Making Models

2.1. Conceptual views

In Figure 1 we present three conceptual views of the decision-making process. They may be regarded as meta-models, since they serve to build other models. The first view regards the decision process as a production system having three components: inputs, process and outputs [8]. The process component concerns social interaction with support from technology in three main forms: decision aids; managing the decision process; and adoption of emerging structures to enhance decisions. This conceptual view is highly prevalent in the research field [9].

The second view regards decision making as a composition of data management, model management and dialogue management [10]. Of most importance in this view is model management, which is responsible for controlling the strategic, tactical and operational decisions of the decision makers through technology support.

The third model was originally proposed by Seligmann et al. [11] and later on adopted by Vreede et al. [12] to conceptualize the different aspects that set up the technological support to the decision-making process. The way of thinking concerns thinking about the application domain, while the way of controlling concerns the design approach that follows problem conceptualization. Design is then dependent on two other constructs: the way of working, i.e. how people carry out their activities; and the way of modeling, i.e. the representations necessary to support the way of working. These models highlight that decision models coexist in a complex context characterized by process inputs and outcomes, competing data and dialogue models, and a difficult balance between design constraints and ways of working.

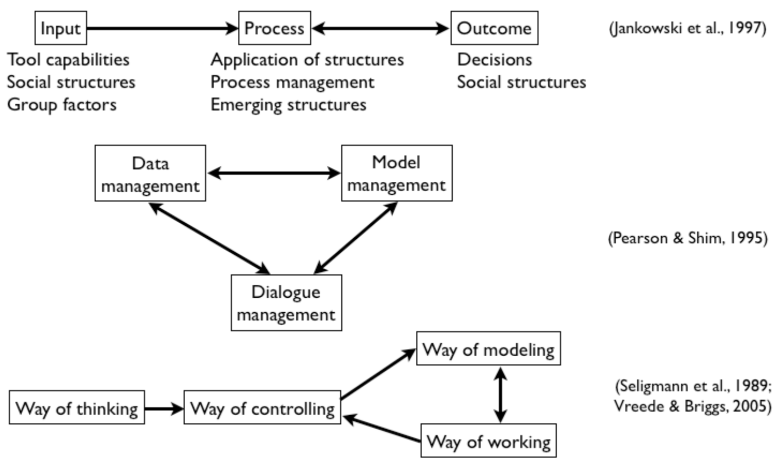

Fig. 1. Conceptual views

2.2. Models of the cognitive process

The models of the cognitive process regard decision-making as a cognitive function. One of the most famous models was proposed by Card et al. [13]. It regards the cognitive function as a machine where stimuli ignite perceptual activities, followed by cognitive and motor activities, which in turn originate new stimuli. In this model, decision-making is a cyclic endeavor continuously supported with feedback information.

This model has been highly influential, the reason why many other models tend to reflect the same information processing view, with most differences centered on the cognitive task. For instance, the Contextual Control Model [14] adopts a similar cyclic view, although with the addition of disturbances, which are fundamental to understand human behavior facing the unexpected. The Reference Model of Cognition [15, 16] extends the cognitive component with interpretation and planning components. The Step Ladder Model [17] also extends the cognitive component with identification, interpretation, task definition and planning components.

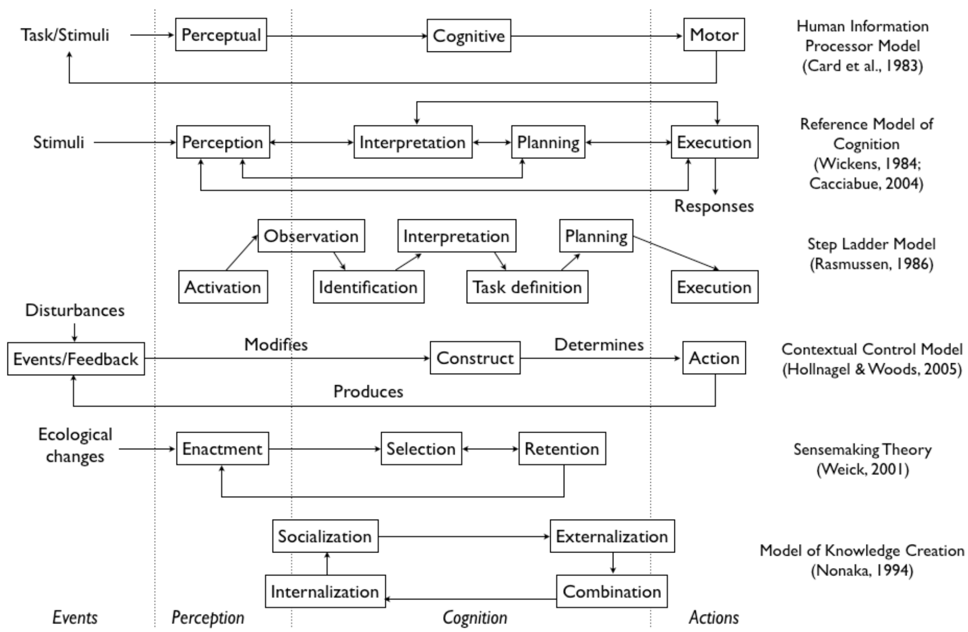

Fig. 2. Models of the cognitive process

Two cognitive approaches that depart away from the perceptual-cognitive-motor mechanics are the Sensemaking theory and the Model of Knowledge Creation. The Sensemaking theory [18] seeks to understand how humans deal with information through their equivocal perceptions and cognitive biases. Ecological changes enact perception according to commitment and interpretation mindsets. Some cues are selected, made intelligible and retained. Retention is important to understand how organizations learn. Perhaps the main conceptual change proposed by sensemaking, when compared to the previous models, is that it moves away from reproducing an information-processing machine towards a more ambiguous cycle, highly dependent on retention.

The Model of Knowledge Creation [19] seeks to understand how humans utilize tacit and explicit knowledge. Knowledge is transformed from tacit (in the mind) to explicit (in the world) through a cycle of data socialization, externalization, combination and internalization. This model highlights the main differences between individual (internalization and externalization) and group (socialization and combination) functions.

In Figure 2 we present a visual representation of the reviewed models. We note that this representation is necessarily incomplete. It primarily serves to highlight that the decision-making process seems to be grounded on four main theoretical constructs: events, perception, cognition and actions. The main differences posited by these models seem to be centered on the cognition construct. In the next section we will further analyze this particular construct.

2.3. Models of the decision process

Likewise the cognitive process, many models have been proposed to explain the decision process. One highly influential perspective is the Subjective Expected Theory [20, 21]. This theory considers that rational decision makers, when facing a set of alternatives and outcomes, define utility functions to determine which choices should be elected. This theory is the basis for what has been designated normative approach to decision making under uncertainty [20].

Other theories have followed the normative approach, e.g., Analytic Hierarchy Process (AHP) [22]. AHP commends four major steps in making decisions: break down the problem into a hierarchy of decision elements; collect data regarding these elements using pair-wise comparisons; estimate the relative weights of decision elements; and aggregate the relative weights to obtain a set of ratings for the decision alternatives.

Simon [23, 24] criticizes the normative approach for its perfect utility-maximizing rationality, emphasizing that in real-world organizations decision makers do not find the perfect conditions necessary to frame problems. Simon proposed the Problem Solving Model with three main elements: representing the problem, finding alternatives and selecting alternatives (often designated intelligence, design and choice). Two other distinctive concepts in this model are heuristics and the notion of satisficing. Heuristics explain why decision makers often simplify the problem space by applying means-ends analysis, compromises, time constraints and even rules of thumb. The notion of satisficing explains that often the decision makers do no aspire to maximize utility but instead seek to find out a solution that satisfies reasonable conditions.

The Recognition Primed Decision Making theory (RPDM) [25] introduced the naturalistic perspective over decision making [26]. This perspective distinguishes itself from the previous approaches by trying to understand how time pressure, uncertainty, ill-defined goals and other factors affect the decision makers. Instead of trying to define how to make decisions, the naturalistic perspective seeks to understand how decisions are actually made. RPDM thus stresses three fundamental components of decision-making: experience the situation, recognize and classify, and react. This theory also brings forward the concept of situation awareness as a mechanism to apprehend expectancies, cues, goals and actions.

Besides the rational-versus-organizational-versus-naturalistic debate briefly described above, many other theories seek to explain more specific conditions underlying the decision-making process. For instance, the Cooperative Decision Making model [27] emphasizes the importance of negotiating conflicts. The Participatory Decision Making model [28] distinguishes between divergent and convergent collaboration modes. The Soft Systems Methodology (SSM) [29] proposes a conceptual approach to problem solving based on action research, coping iteratively with problem complexity while at the same time avoiding reductionism. SSM highlights action as a fundamental driver for problem solving, instead of analysis and structure. And finally, Collaboration Engineering [30] synthesizes decision-making as a collection of behavioral patterns that may be "engineered" to respond to contextual situations.

In Figure 3 we may observe the impact of the Problem Solving Model and it's threefold construct (intelligence, design and choice) on understanding the decision-making process. We also find a relative consensus that this logical construct is considered cyclical and not necessarily prescriptive.

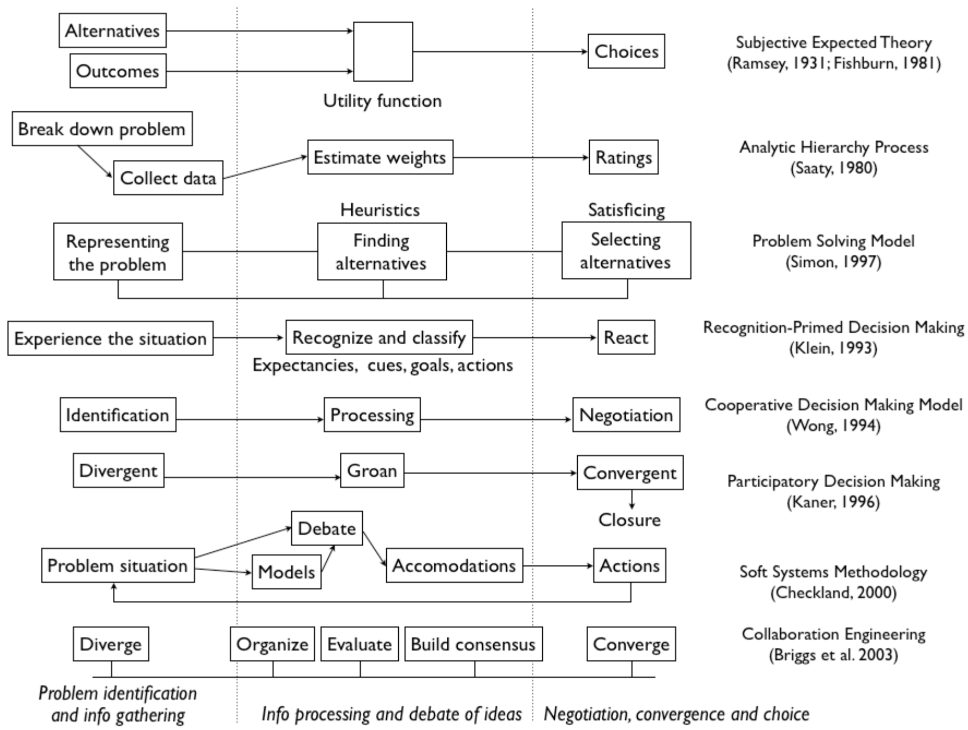

Fig. 3. Models of the decision process

2.4. Discussion and synthesis

What can we distill from the above models? First, decision-making involves a constant flow of events, perception, cognition and action. Second, the cognitive activity seems to be organized according to three main patterns: (1) problem identification and information gathering; (2) information processing and debate of alternatives; and (3) negotiation, convergence and choice. And third, decision-making also involves data management, dialogue management and model management. Model management is fundamentally concerned with structuring the main patterns previously identified. Furthermore, model management is intimately related with the way of thinking, controlling and working. From this integrated perspective we may now derive some fundamental requirements to CSDM:

Perception support. Stimuli, disturbances, events and ecological changes are necessary to stimulate perception. CSDM should therefore associate changes in spatial data with adequate perceptual mechanisms, e.g., dynamic visualization, strategic and tactical views of spatial data and associated events.

Retention support. Retention is a fundamental driver of sensemaking. It serves to construct personal and organizational memory and contributes to enact responses whenever recognizable situations emerge. CSDM should maintain a repository of the interpretation mindsets and enacted responses in context with spatial data.

Externalization support. Externalization is essential to knowledge creation, since knowledge is constructed by articulating tacit knowledge into shared expectancies, cues, goals and actions. CSDM should therefore provide support for integrating tacit knowledge with spatial data.

Divergent/convergent support. Decision-making seems to be organized according to intertwined cycles of divergent and convergent activities, where divergent activities favor problem identification and information gathering, and convergent activities promote the negotiation and selection of alternatives. CSDM should support these working modes.

Recognition support. Recognition and classification play a fundamental role in the naturalistic approach to decision-making. Recognition prepares the ground for empirical decisions based on situation awareness and pattern matching. CSDM should therefore provide situation-action support by linking spatial data with expectancies, cues, goals and actions defined by the decision makers.

Task/pattern management. The decision-making process seems to be organized according with patterned activities like divergence, convergence, data organization, option evaluation, etc. Several theories posit these patterned activities are iterative/cyclic and may not follow a prescriptive or recommended structure. Thus, although CSDM should carefully avoid prescribing rigid structures, they should also support the way of controlling by implementing task/pattern management.

3. Literature Analysis

We adopted the following approach to analyze CSDM literature. First, we started by collecting papers published in journals, conferences and workshops on the subject of enabling working on spatial data while simultaneously making collaborative decisions [31]. This task allowed us to identify a set of 61 papers. We then applied a set of criteria to reduce our review to: (1) papers published from 2000 to 2009; (2) papers focused on the analysis, design, development and evaluation of CSDM applications; and (3) excluding papers centered on literature review, framework and theory development, infrastructure support to CSDM and specific application scenarios. A total of 18 papers were found to fulfill these criteria. We then elected 10 papers as most representative of current CSDM. Table 1 summarizes the elected papers.

Tab. 1. Most representative papers of current CSDM.

	Convertino et al. 2005 [32]	**Rinner 2006 [33]**
Perception	Workspace metaphor, multiple views, filters, activity awareness indicators, change icons	Hypermap metaphor
Retention	Historical records	Retains geo-argumentative relations
Externalization	Has chat, editor and interactive map	Argumentation model
Divergent/convergent	Convergent (tactical planning)	Divergent (early phase)
Recognition	Annotations and visual landmarks	Annotations and visual landmarks
Task/pattern manag.	Only supports roles	
	MacEachren et al. 2006 [34]	**Bortenschlager et al. 2007 [35]**
Perception	Desktop metaphor	Regular updates
Retention		
Externalization	Speech and gesture recognition	Overlays
Divergent/convergent	Convergent (large whiteboard)	Convergent (using mobile devices)
Recognition	Incident markers	
Task/pattern manag.		
	Convertino et al. 2008 [36]	**Capata et al. 2008 [37]**
Perception	Sidebar, telepointer, role indicators	Object push
Retention		
Externalization	Notes, scribbles, symbols	Geographical features
Divergent/convergent	Both (shared and private workspaces)	Both (using mobile devices)
Recognition		
Task/pattern manag.	Only supports roles	
	Brewer et al. 2000 [38]	**MacEachren et al. 2004 [2]**
Perception	Depict change over time, gestures, member behavior, flash regions	Split views, member behavior, avatars, pointing gestures
Retention	Activity logging	
Externalization		Drawing and selection tools
Divergent/convergent	Both	Convergent
Recognition		
Task/pattern manag.		Defines exploration, analysis, synthesis and presentation tasks, but does not implement
	Cai 2005 [39]	**Torino et al. 2001 [40]**
Perception	Change propagation	
Retention		
Externalization	GIS workspace, group summary	Stands and seeds (markers)
Divergent/convergent	Convergent (large displays)	Divergent (using shared database)
Recognition	Marking	Conflict detection (with markers)
Task/pattern manag.		

From this overview we may draw some observations and comments. Our first observation is that none of the reviewed CSDM tools addresses task/pattern management.

Actually, only [2] refers to the importance of managing decision-making tasks, although such functionality is not implemented in the prototype.

Another issue is related with divergent/convergent support. Most reviewed CSDM tools support either convergent or divergent activities, with only three cases supporting both modes [36-38]. But more interestingly, the tools supporting both modes do so in a transparent way, i.e. the users may converge and diverge according to factors such as network connectivity or interaction with private and public spaces. These tools do not explicitly define if work is divergent or convergent according to the specific task at hand.

Most tools do not support retention, with few exceptions supporting activity logging and historical records [32, 33, 38]. Perception has received significant attention, with multiple mechanisms being available. The recognition support is apparently less rich. Several tools support annotations and markers [32, 33, 39, 40] but miss more strategic features linking spatial data with expectancies, cues, goals and actions. Finally, externalization combines GIS features with common groupware functionality like chat, text editing and argumentation. This review clearly indicates our research and development efforts should be centered on the support to: (1) task/pattern management; (2) explicit convergent/divergent collaboration modes; (3) retention; and (4) recognition.

4. E-Planning Tool

Like most CSDM tools reviewed in the previous section, the e-planning tool has a workspace allowing visualizing and interacting with a map. This map may be complemented with spatially related visual objects like sketches, drawings and free-hand text, collaboratively produced by the users to enhance their **perception**.

Unlike the other tools, we also support **task/pattern management**. This is implemented with multiple workspaces, targeted to specific tasks/patterns (see Figure 4). The set of tasks/patterns was derived from the Problem Solving Model: (1) gathering, (2) debate, and (3) choice. We stipulate that all users operate in the same workspace, but they may collectively change the current workspace whenever necessary. This avoids a prescriptive approach to making decisions. Mini-maps allow visualizing the three workspaces and also serve to select the current workspace.

Externalization is supported with sketching, drawing and text writing in the workspace. **Retention** is based on logging changes to the visual objects present in the workspace, allowing the users to move back and forth the timeline. To support **recognition**, the tool allows selecting annotations (sketches, drawings, text) from one workspace and dragging them to another workspace (using the mini-maps).

We define the gathering workspace is **divergent** and the debate and choice workspaces are **convergent**. This allows users' free whiling and divergent thinking while gathering information, but requests the users' focus while debating and choosing options.

The tool runs on tablet computers and may be used in several physical configurations, including a set of interconnected tablets, one large whiteboard or a combination of both.

Our prototype uses SMARTech's SmartBoard. The prototype adopts a fully replicated architecture and is heavily based on pen-based gestures to interact with the user interface [41]. When a replica is started in a tablet, it automatically establishes an ad-hoc network with the other tablets and synchronizes all spatial data.

The tool's user interface is shown in Figure 4. The current workspace is shown on the left handside. The participants may use the pen to sketch and write over the map. The mini-maps are shown to the right. They support two functions. One is moving the group's focus of attention to a different workspace (the dark background color indicates what workspace is currently selected). As previously mentioned, three different workspaces are supported. The one on the top is the gathering workspace, the one in the middle is the debate workspace, and the lower one is the choice workspace.

Another important functionality is indexing the data elements created over the map. Each index entry has a set of sketches consecutively made by one user. In Figure 4, the gathering and debate workspaces show two index entries each. These indexes simplify the selection and edition of individual data elements using gestures. The mini-maps support vertical scrolling but do not use a scrollbar to preserve space.

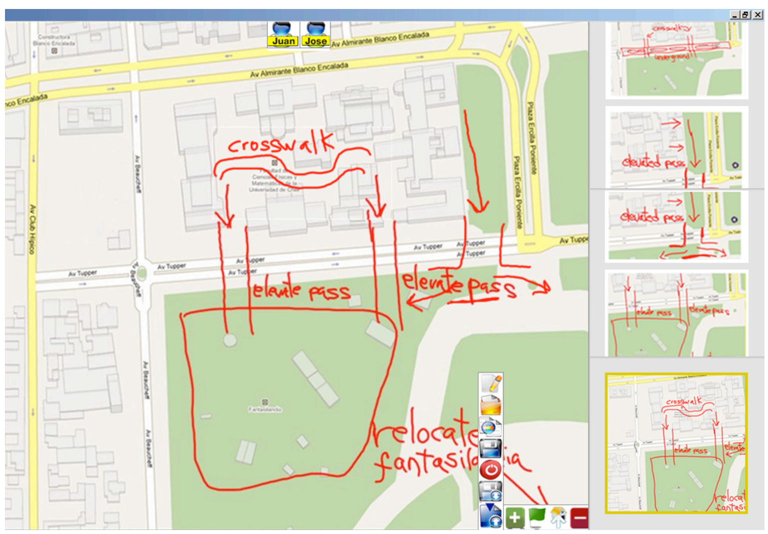

Fig. 4. The e-planning tool

The data elements may be copied from one workspace to another. The copy and paste operations are performed at a granularity that considers index entries, not individual sketches. The origins and destinations of the copy/paste operations are either the current workspace or the mini-map. The pasted data elements maintain their spatial references. It is possible to scroll and zoom over the map and related data elements. The icons located on the center-top of the screen provide awareness on who is currently using the tool.

We now describe in more detail the functionality associated with each workspace. The **gathering workspace** operates in a divergent mode. This means the workspace is private and the data elements sketched over the map are not shared with the group. This collaboration mode allows users to prepare their ideas before sharing them with the others. When necessary, a user may share a particular data element with other users. Selecting the corresponding index entry and dragging it to the users' icons shown at the center-top of the screen accomplish this.

The **debate workspace** serves to explore and refine ideas. This is a convergent task involving all users. Initially this workspace only shows the map, but allows users copying index entries from their individual gathering workspaces using pen-based gestures. In this way the users may share, organize and refine the set of common ideas.

The **choice workspace** operates in a very similar way. It is initially empty and may be populated by copying index entries from the debate workspace. This workspace is intended to develop a final visual representation of the decisions made by the group.

5. Case Scenario and Evaluation

The main challenge addressed by this research was supporting decision making within the spatial context. We regarded this challenge from a design science perspective, i.e., seeking to extend human and organizational capabilities through innovative artifacts [42]. It thus makes sense to also evaluate the proposed solution using a design science approach. According to Hevner et al. [42], design solutions must be justified/evaluated with the twofold purpose to improve artifacts and develop theory. One possible evaluation approach consists in evaluating the utility of the design artifact using controlled experiments. In this section we report a preliminary field trial with the e-planning tool.

We asked a team of three people to perform an e-planning task considering the plans of the municipality of Santiago to merge the area occupied by the Faculty of Engineering of the Universidad de Chile with the nearby-located park, now separated by an avenue. The task was divided in two sessions during which the team had to use the e-planning tool to generate ideas on how to create a continuous area from the faculty to the park.

During the first session, two team members worked in the field using their Tablet PCs, documenting their ideas in the gathering workspace. In the second session, they joined the third member in the office. The third member used a SmartBoard while the other two members kept using their Tablet PCs (Figure 5).

After synchronizing the applications, the members started exposing their solutions and discussing using the debate workspace. New alternatives were generated and indexed in this workspace. Finally, in the choice workspace all members collaboratively developed the final solution, which in fact was a merge of the two proposed solutions.

Fig 5. Using the e-planning tool in the second working session

In the end of the experiment we asked the participants to analyze the prototype usage in the predefined scenario and come up with comments and observations regarding its utility. The discussion confirmed the divergent collaboration mode is beneficial to the initial decision stages, where the decision makers seek to generate ideas. Externalization was considered adequately implemented by the prototype. It was explicitly noted the sketches helped exteriorizing and sharing tacit knowledge.

The pen-based gestures were considered easy to use, although more traditional interaction modalities based on mouse and keyboard were also requested. The choice workspace was perceived as the most helpful one because it is focused on bringing the group towards the task goals and, at the same time, allows importing information from the other tasks in a flexible way. The debate workspace was also perceived as very helpful to organize ideas through sketches and concept maps.

Overall, the prototype was perceived as relevant to e-planners because it enables people to contribute, explain, exteriorize and share their ideas in relation with spatial references. Nevertheless, the participants suggested improving the recognition abilities, considering a major challenge the implementation of adequate awareness mechanisms. Finally, the participants considered the learning curve was adequate, commenting they were adapted to the prototype during the second session.

6. Synthesis and Discussion

The main contributions of this work include an integrated perspective of the relationships between spatially related data and decision-making. To build this integrated perspective, we analyzed an extensive pool of models explaining the cognitive behaviors associated with decision-making. We then distilled six requirements: perception, retention, externalization, recognition, divergent/convergent collaboration modes, and task/pattern management. Perception emphasizes a cognitive view over the decision-making process. It brings forward the need to convey spatially-related data in a way that stimulates decision makers to perceive and enact cognitive functions like identification, interpretation, selection, task definition, planning, externalization, action, etc.

Retention addresses the withholding of personal and organizational experiences, resulting from the confrontation between events and actions, interpretations, choices and other constructs. Retention is a fundamental driver for sensemaking, and sensemaking is a fundamental driver for making decisions. In the CSDM context, we understand the retention requirement as the need to preserve decisions, decision constructs and spatial data in a coherent framework that promotes learning and recall.

Externalization brings forward the view that decision-making is a collective endeavor and knowledge must be transformed from tacit to explicit. This signals that decision makers should be able to collaboratively manage spatially related data. Recognition is closely associated with a naturalistic view over decision-making where emergence, time pressure and uncertainty give the fundamental context to understand choices. In the CSDM context, this requirement renders the collaborative creation of annotations, visual marks and other spatially-related visual elements that contribute to react to evolving situations.

The divergent/convergent view brings forward the understanding that teams must devise strategies to optimize collective tasks. Often the best strategy is focusing on the same task, while in other cases is having the participants working independently. We regard flexible management of collaboration modes a fundamental requirement of CSDM.

The consideration for task/pattern management highlights the view that decision makers should be able to control the tasks necessary to reach their goals. In the CSDM context, this means that task/pattern management should be explicitly available, although avoiding prescribed procedures.

Our review of the state of the art shows that existing CSDM tools offer adequate levels of perception, retention and externalization support. However, divergent/convergent and task/pattern support seems to be underdeveloped. Of course we had to verify if these requirements would have some concrete impact on CSDM design. We developed an e-planning tool with that goal in mind. We codified the requirements into concrete functionality. In particular, we structured the tool in three working spaces specifically dedicated to support problem representation, finding alternatives and selecting alternatives. Each working space maintains the decision-making elements according to their spatial context. This functionality implements the task/pattern management requirement.

Of the three workspaces, one supports divergent activities while the other two support convergent activities. This decision was drawn from theory recommending the adoption of divergent activities during the preliminary decision phases and convergent activities during the later decision phases [28]. Divergence was implemented with private workspaces, while convergence relies on shared workspaces supporting concurrent data management. This functionality implements the divergent/convergent requirement.

The perception, recognition and externalization requirements were resolved with a set of visual elements the users may create and manipulate using pen-based gestures. These elements are spatially related since a map always exists in the workspaces. A team evaluated the tool in a laboratory experiment and considered it useful and usable.

Nevertheless, we should discuss some limitations we find in this study. One limitation is that we do not attempt to define a unifying decision-making theory. It may perhaps be attempted in a future work, and significant groundwork has already been done, for instance bringing together the cognitive and decision-making models. But this endeavor requires additional work to demonstrate the validity of its constructs. What we have done instead was focusing on design-oriented goals, deriving a set of requirements from the various theories. This approach is much more simple to validate: we just have to build a tool and justify its utility, as recommended by Hevner et al. [42].

Nevertheless the justification of the tool will require future work. More scenarios, experiments, participants and inquiries are necessary to validate it. We should also consider in the future moving out from the laboratory to the field, which will require developing further the prototype to improve its overall stability.

We also recognize that the perception, recognition and externalization requirements were underdeveloped when compared with the other requirements. Indeed our main focus was on the requirements we perceived as most neglected by the CSDM literature. But in retrospect we perceive that many contributions to better implement these requirements could be done in the future. Particularly, we may further explore the perception and recognition requirements in the context of team situation awareness [43]. This perspective may bring forward new technological mechanisms capable to improve the perception of the dynamics often associated to spatially-related data.

Acknowledgements. This paper was supported by the Portuguese Foundation for Science and Technology (PTDC/EIA/102875/2008) and Fondecyt.

References

1. Curwell, S., Deakin, M., Cooper, I., Paskaleva-Shapira, K., Ravetz, J., Babicki, D.: Citizens' Expectations of Information Cities: Implications for Urban Planning and Design. Building Research and Information 33, 55-66 (2005)
2. MacEachren, A., Brewer, I.: Developing a Conceptual Framework for Visually-Enabled Geocollaboration. International Journal of Geographical Information Science 18, 1-34 (2004)
3. MacEachren, A.: Moving Geovisualization toward Support for Group Work. In: Dykes, J., et al. (eds.) Exploring Geovisualization, pp. 445-462. Elsevier (2005)
4. Nyerges, T., Montejano, R., Oshiro, C., Dadswell, M.: Group-Based Geographic Information Systems for Transportation Site Selection. Transportation Research C 5, 349-369 (1997)

5. Armstrong, M.: Requirements for the Development of Gis-Based Group Decision Support Systems. Journal of the American Society for Information Science 45, 669-677 (1994)
6. Arnott, D., Pervan, G.: A Critical Analysis of Decision Support Systems Research. Journal of Information Technology 20, 67-87 (2005)
7. Crossland, M., Wynne, B., Perkins, W.: Spatial Decision Support Systems: An Overview of Technology and a Test of Efficacy. Decision Support Systems 14, 219-235 (1995)
8. Jankowski, P., Nyerges, T., Smith, A., Moore, T., Horvath, E.: Spatial Group Choice: A Sdss Tool for Collaborative Spatial Decision-Making. International Journal of Geographical Information Science 11, 577-602 (1997)
9. Fjermestad, J., Hiltz, S.: An Assessment of Group Support Systems Experimental Research: Methodology and Results. Journal of Management Information Systems 15, 7-149 (1999)
10. Pearson, J., Shim, J.: An Empirical Investigation into DSS Structures and Environments. Decision Support Systems 13, 141-158 (1995)
11. Seligmann, P., Wijers, G., Sol, H.: Analysing the Structure of IS Methodologies. In: Proceedings of the 1st Dutch Conference on Information Systems, Amersfoort, The Netherlands (1989)
12. Vreede, G., Briggs, R.: Collaboration Engineering: Designing Repeatable Processes for High-Value Collaborative Tasks. In: Proceedings of the 38th Hawaii International Conference on System Sciences, Hawaii (2005)
13. Card, S., Moran, T., Newell, A.: The Psychology of Human-Computer Interaction. Lawrance Elrbaum, Hillsdale, NJ (1983)
14. Hollnagel, E., Woods, D.: Joint Cognitive Systems: Foundations of Cognitive Systems Engineering. CRC Press (2005)
15. Wickens, C.: Engineering Psychology and Human Performance. Charles Merrill, Columbus, OH (1984)
16. Cacciabue, P.: Guide to Applying Human Factors Methods. Springer, London (2004)
17. Rasmussen, J.: Information Processes and Human-Computer Interaction. An Approach to Cognitive Engineering. North Holland, Oxford (1986)
18. Weick, K.: Making Sense of the Organization. Blackwell, Oxford, UK (2001)
19. Nonaka, I.: The Knowledge-Creating Company. Harvard Business Review, 96-104 (1991)
20. Fishburn, P.: Subjective Expected Utility: A Review of Normative Theories. Theory and Decision 13, 139-199 (1981)
21. Ramsey, F.: Truth and Probability. In: Ramsey, F. (ed.) The Foundations of Mathematics and Other Logial Essays. Harcourt, Brace & Co., New York (1931)
22. Saaty, T.: The Analytical Hierarchy Process. McGraw-Hill, Inc. (1980)
23. Simon, H.: Administrative Behavior: A Study of Decision-Making Processes in Administrative Organizations (4th Edition). Free Press, New York (1997)
24. Simon, H.: Decision Making and Problem Solving. INTERFACES 17, 11-31 (1987)
25. Klein, G.: A Recognition-Primed Decision (Rpd) Model of Rapid Decision Making. In: Klein, G., et al. (eds.) Decision Making in Action: Models and Methods. Ablex, Norwood, CT (1993)
26. Lipshitz, R., Klein, G., Orasanu, J.: Taking Stock of Naturalistic Decision Making. Journal of Behavioral Decision Making 14, 331-352 (2001)
27. Wong, S.: Preference-Based Decision Making for Cooperative Knowledge-Based Systems. ACM transactions on information systems 12, 407-435 (1994)
28. Kaner, S.: Facilitator's Guide to Participatory Decision-Making. New Society Publishers, Philadelphia, PA (1996)
29. Checkland, P.: Soft Systems Methodology: A Thirty Year Retrospective. Systems Research and Behavioral Science 17, S11-S58 (1981)

30. Briggs, R., Vreede, G., Nunamaker, J.: Collaboration Engineering with Thinklets to Pursue Sustained Success with Group Support Systems. Journal of Management Information Systems 19, 31-64 (2003)
31. MacEachren, A., Cai, G., Sharma, R., Rauschert, I., Brewer, I., Bolelli, L., Shaparenko, B., Fuhrmann, S., Wang, H.: Enabling Collaborative Geoinformation Access and Decision-Making through a Natural, Multimodal Interface. International Journal of Geographical Information Science 19, 293-317 (2005)
32. Convertino, G., Ganoe, C., Schafer, W., Yost, B., Carroll, J.: A Multiple View Approach to Support Common Ground in Distributed and Synchronous Geo-Collaboration. In: Proceedings of Third International Conference on Coordinated and Multiple Views in Exploratory Visualization, London, UK, pp. 121-132. IEEE Computer Society (2005)
33. Rinner, C.: Argumentation Mapping in Collaborative Spatial Decision Making. In: Balram, S., Dragićević, S. (eds.) Collaborative Geographic Information Systems. Idea Group Publishing Hershey, PA (2006)
34. MacEachren, A., Guiray, C., Brewer, I., Chen, J.: Supporting Map-Based Geocollaboration through Natural Interfaces to Large-Screen Displays. Cartographic Perspectives 54, 4-22 (2006)
35. Bortenschlager, M., Leitinger, S., Rieser, H., Steinmann, R.: Towards a P2P-Based Geocollaboration System for Disaster Management. In: GI-Days 2007 - Young Researchers Forum (2007)
36. Convertino, G., Mentis, H., Bhambare, P., Ferro, C., Carroll, J., Rosson, M.: Comparing Media in Emergency Planning. In: Proceedings of the 5th International ISCRAM Conference, Washington, DC (2008)
37. Capata, A., Marella, A., Russo, R.: A Geo-Based Application for the Managemnt of Mobile Actors During Crisis Situations. In: Proceedings of the 5th International ISCRAM Conference, Washington, DC (2008)
38. Brewer, I., MacEachren, A., Abdo, H., Gundrum, J., Otto, G.: Collaborative Geographic Visualization: Enabling Shared Understanding of Environmental Processes. In: Proceedings of IEEE Symposium on Information Visualization, Washington, DC, pp. 137 (2000)
39. Cai, G., MacEachren, A., Brewer, I., McNeese, M., Sharma, R., Fuhrmann, S.: Map-Mediated Geocollaborative Crisis Management. Intelligence and Security Informatics. LNCS, vol. 3495, pp. 429-435. Springer Verlag, Heidelberg (2005)
40. Touriño, J., Rivera, F., Alvarez, C., Dans, C., Parapar, J., Doallo, R., Boullón, M., Bruguera, J., Crecente, R., González, X.: Copa: A Ge-Based Tool for Land Consolidation Projects. In: Proceedings of the Ninth ACM International Symposium on Advances in Geographic Information Systems, Atlanta, Georgia, pp. 53-58. ACM Press (2001)
41. Zurita, G., Antunes, P., Baloian, N., Baytelman, F., Farias, A.: Visually-Driven Decision Making Using Handheld Devices. In: Zaraté, P., et al. (eds.) Collaborative Decison Making: Prospectives and Challenges. Frontiers in Artificial Intelligence and Applications, pp. 257-269. IOS Press, Amsterdam, The Netherlands (2008)
42. Hevner, A., March, S., Park, J., Ram, S.: Design Science in Information Systems Research. Management Information Systems Quarterly 28, 75-105 (2004)
43. Salmon, P., Stanton, N., Jenkins, D., Walker, G., Young, M., Aujla, A.: What Really Is Going On? Review, Critique and Extension of Situation Awareness Theory. Engineering Psychology and Cognitive Ergonomics, vol. 4562, pp. 407-416. Springer, Heidelberg (2007)