Supporting Environmental Planning: Knowledge Management Through Fuzzy Cognitive Mapping

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Abstract. The inherently complex nature of the environmental domain requires that planning efforts become projects of participated, inclusive, multi-agent, multi-source knowledge building processes developed by the community. Knowledge is often hard to be processed, handled, formalized, modeled. Yet cognitive models are useful to avoid the typical unmanageability of domains with high complexity such as the environmental one, and enhance knowledge organization and management. We have investigated on the potentials of cognitive-mapping-based tools, particularly on cross impact evaluations, in the case study of Taranto (Italy). The process was aimed at building up future development scenarios in city neighborhoods, and fuzzy cognitive mapping were used to support decision-making by exploring cross impacts of possible policy perspectives. Although substantial results are rather general, the study proves to be interesting in enhancing the potentials of FCM-based approach to support decision-making, particularly when dealing with well-focused policy perspectives.

Keywords: Fuzzy cognitive mapping · Environmental planning · Decision support system · Multiple agents

1 Introduction

The environment is today firmly considered as a complex system by planning literature. In such conditions, planning initiatives affecting the environmental domain (i.e., environmental planning) are intrinsically knowledge demanding, in order to cope with such complexity and aim at effective future strategies. Yet, knowledge is nowadays considered as a multiform, multi-agent, dynamic disposition, being complex as it mirrors the phenomenological-relational complexity of the environment it refers to [1]. Environmental knowledge heavily depends on knowledge holders, i.e., all the community agents who use and/or build knowledge because of their study, their work, their behavior, their life. As a matter of fact, knowledge contents useful in planning efforts are not a

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prerogative of traditional –rational- domain experts, i.e. scholars, professionals, researchers, technicians. Rather, knowledge is strictly connected to and reflecting on action, i.e., a prerogative of all expert and non-expert agents [2–4].

Planning efforts become projects of participated, inclusive, multi-agent, multisource knowledge, in which the community develops the building up of future visions and scenarios, as expert and non-expert agents [5]. Future scenarios are necessary substantial issues in this context, yet formal issues become particularly critical here, too. In fact, namely non-expert knowledge is often informal, puzzling, uncertain, and incomplete: complex, as mirroring the environmental complexity it refers to. As often reported by literature, social/environmental knowledge is often hard to be treated, handled, formalized, modeled. Yet cognitive models prove to be useful toward avoiding the typical unmanageability of domains with high complexity such as the environmental one, and to enhance knowledge organization and management [6]. Models are a basis for the building up of system architectures useful to support multi-agent interactions, decision-making, land use, policy-making and planning [7].

Therefore, a research question arises now, about how to build such a model that allows the management of complex environmental knowledge. Although qualitative knowledge contents are hardly manageable, strictly quantitative databases often imply rigid knowledge patterns, reductionist syntheses of phenomena and processes, often too deterministic and unable to represent the complex aspects they aim at investigating and measuring [8]. However, an ICT-based approach to knowledge analysis is able to enhance the possibility of handling both qualitative and quantitative data, formal as well as informal contents, through opportune modeling approaches.

Our research group has been deeply involved in such activity in the last decades. ICT-based, automatic as well as semi-automatic and hybrid (mixed) approaches have been carried out and accounted for in previous editions of CDVE Conferences. It has always been characterized as a case-based approach, in which experimentations were carried out where methodologies were tested and discussed in the real world (e.g., [5, 9, 10]). In recent years, the methodological focus has been slightly shifted from general, platform-oriented approaches to tools and methods. We have investigated on the potential of cognitive-mapping-based tools, particularly on cross impact evaluations. Fuzzy cognitive mapping (FCM) were dealt with in particular, as a great number of applications have been implemented with good significance [11, 12]. In our case studies, models based on FCM have allowed the use of local stakeholders' knowledge for ecological modeling and environmental management in participatory, interactive management schemes. As found out experimentally, FCMs could also be used as a qualitative tool for the stakeholder representation of environmental problems, with a multi-agent approach [13, 14].

The experimentation of the present paper is carried out in the scenario-building activity from the design process of the new master plan of Taranto (Italy). The Taranto case study is very intriguing for our aims, as it is a paradigmatic example of harshly decaying industrial community, today heavily fragmented with jobless redundancy and environment degradation [15]. A number of focus group sessions carried out among the community stakeholders represent the basis for a FCM-based analysis. They are aimed at modeling future visions and strategies, structuring environmental problems and analyzing the sensitivity of multi-agent-based policy-making decisions in planning strategies.

After the present introduction, Chap. 2 describes the experimentation layout, whereas Chap. 3 discusses the FCM-based outcomes. Brief remarks end up the work.

2 FC Mapper Application and Case-Study Description

Within the present case study, data analysis and processing is carried out by structurally and ontologically involving cognitive interactions with their inherent substantial contents and mutual connections, drawing on a fuzzy-logic based tool, called FCMapper. This is a soft-system modeling and mapping approach combining qualitative and quantitative methods, with a participative social–learning approach [14]. FCM is aimed at quantifying abstract concepts and turning them into data on which to build up future scenarios. It tries to reveal and structure emergent possibilities in complex systems such as urban settlements.

Concerning the case-study, this tool has been used to build a model of an environmental-urban system structure, by formalizing and explaining some causal links between the main elements. In particular, the nodes of maps represent system variables and weighted arcs represent causal dependencies among concepts. As a matter of facts, the interaction between concepts shows the dynamic of the system [16].

Indeed FCM approach was significantly affected by the work of Kosko [17]. He modified Axelrod's cognitive maps by applying fuzzy casual functions with real numbers (-1 to 1) to connections [18]. The positive sign indicates a positive causality, the negative one expresses a negative causality between nodes [19]. FCM simulations give structured hints on how the system will change over time, analyzing how the implementation of a specific policy affects some variables and consequently causes changes in the entire map. Therefore, in the scenarios analysis phase, FCM expresses the effects on the system by a certain policy implemented as a change of a particular node strength or of a certain value of causal relationship.

In this study, the aim of FCM is to support the decision-making process in the field of urban empowerment and improvement. Specifically, FCM is applied to single out major problems affecting the city of Taranto based on the distributed knowledge of people, in order to design and evaluate policy possibilities to minimize their negative effects and improve city livability.

In 2014, a number of meetings with citizens took place in Taranto neighborhoods. Three of those interaction sessions are taken into account in this study, aiming at comparing situations in different environmental contexts. Therefore, we started from three different cognitive maps built on the information statements collected. These maps are designed through a process of participatory knowledge interaction based on scenario-building methodologies and slightly modified from Khakee et al. [20]. The maps are named according to the neighborhood location in which the meetings took place: *Città Vecchia, San Vito* and *Torretta.* Each neighborhood represents specific points of view on city problems even if they are often in the same problem field.

People attending the meetings were first grouped around tables. Afterwards, they entered their views (under the form of written statements) about their neighborhood on graphical cognitive maps, displayed on the available laptops for this task.

Many problem statements expressing similar meanings were clustered according to the evaluations of expert agents into twenty-five summary items (symbolized by A1 to E3 letters), representing the core concept of each problem field. Furthermore, these twenty-five items are used as input variables in the FCM matrix, aggregated into five general areas, i.e., *(A) Community security, (B) Natural environment, (C) Infrastructures, (D) Urbanized and cultural environment, (E) Economy and society.*

Subsequently, these items are organized into adjacency matrices, one matrix for each chosen neighborhood is composed. Thus, the expert agents use a direct fuzzy linguistic weight function to define the value of the reciprocal causal influence for each couple of variables on the matrix [17]. Therefore they assign a positive or negative sign and a value of 0, 5 or 1 to express the grade of casual relationship among concepts [14]. It is important to note that the causal relationship is not necessarily reversible. A confronting round among expert agents is used to choose final, shared values for each matrix cell.

After applying the *Pajek* visualization tool to the FCM matrices, the maps are shown in 2D projection. Main concepts are presented in circles with different colors, one for each general area, and the causal links between the main variables are shown through oriented arcs among nodes. The three maps are examined individually and also compared with each other, in order to find out similarities and differences. After a detailed comparison, only the two city contexts of *Città Vecchia* (CV, inner city) and *San Vito* (SV, a seaside neighborhood) proved to be suitable for further analysis (Fig. 1).

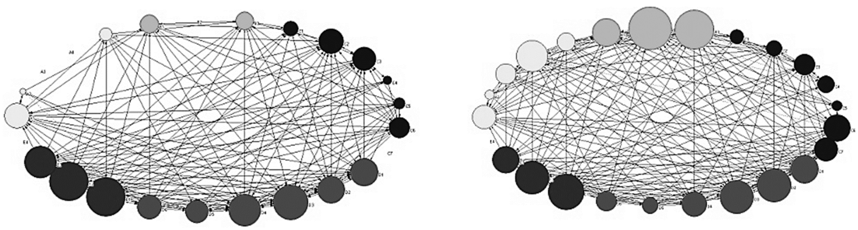

Fig. 1. Views of *Città Vecchia* and *San Vito* fuzzy map projections – circular layout.

Therefore, map structures are observed to investigate the outcomes of different policy choices through the comparison of alternative future scenarios. These scenarios are obtained by artfully influencing certain variables, broadly following a sensitivity-analysis approach. This methodology produces a rearrangement of each map structure, showing the effects that the alternative choices could induce in relation to the other system's variables. The next chapter illustrates this process.

3 Discussion

In two different case studies, we analyzed variables values, corresponding to specific attributes of the adjacency matrix: high centrality, *outdegree* and *indegree*. Specifically, Papageorgiou and Kontogianni [18] define *outdegree* and *indegree* as the cumulative strengths of connections respectively as row and column sums of absolute values. Instead, *centrality* measures map complexity and shows how one variable is connected to other variables and what is the cumulative strength of these connections.

In particular, in *San Vito* high values of centrality are visible in items B2, B3 (environment protection), E1, E2 (planning and design), D1, D2, D3 (building and natural decay), ranging from 22.50 to 14.00. In *Città Vecchia*, the centrality of items D1, D2, D3, D4, E1, E2, E3 is significantly high (28.00–19.50), whereas the centrality of B3 is lower (13.00) and B2 is an unconnected item. In this case-study, variables A1 (vandalism), C2, C3 (infrastructure) are also meaningfully high (18.00–17.00).

In both case studies we worked out and compared two similar scenarios. On the one hand, scenario A simulates the results of implemented policies. It concerns active/proactive actions in a frame of medium/long term planning and oriented to the protection and enhancement of local resources. On the other hand, scenario B focuses on a dual active/reactive and long/short time perspective. This scenario is more general then the first one and is clearly characterized by difficult interpretation and higher level of ambiguity.

The aim of this effort is to compare the effects of similar policies in the two different contexts. The modification of specific initial vectors has been done in order to show the evolution of the map according to clusters. This type of analysis allows investigating "what-if" scenarios by performing simulations of a given model from different initial state vectors. Each vector is a matrix item with high values of centrality, associated with the concepts identified by suggestions and available local knowledge elicited during the focus group sessions.

Using the *Pajek* visualization tool, four maps have been made (the size of the vertices is linked to the input file and represents centrality). In the scenario analysis, the graphical tool allows to understand the positive or negative changes in the map through the different colors and positions that are linked to the input file (deriving from the adjacency matrix elaborated with *FCMapper*). In particular, scenario A maps were drawn using the partition derived from the modification of vectors (value = 1) B2, B3, E1, E2 in San Vito, B3, E1, E2, E3 in *Città Vecchia* and without the modification (value = 0) of vectors D1, D2, D3 and D4. In both case studies, scenario B maps are built through the modification of all the previous vectors.

FCM has been used to explore the values in a group of individuals in order to improve the understanding of a multiple stakeholder decision problem. Starting from the comparison of type-A scenarios (Fig. 2), we can see that the map 'reacts' to changes consistently with centrality values. The general areas are certainly comparable, and changes in item are specific and can be fairly singled out.

Let us deal with a certain policy aimed at preserving and enhancing ecology and natural environment (B2, B3). The policy is using planning actions stimulating local-based economic development (E1, E2) and is drawing also on cultural and artistic heritage, where available (E3). Fuzzy cognitive maps change as follows.

In SV, the only positive –even if "low positive"- change impacts on infrastructures, particularly enhancing slow mobility, whereas in CV it enhances urban security. This difference reflects the context of the maps in the two case studies.

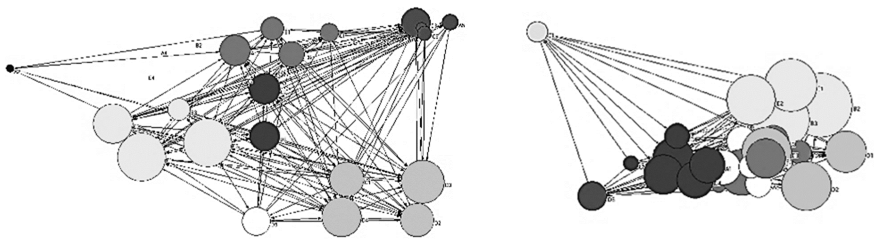

Fig. 2. Scenario A of Città Vecchia and San Vito maps according to the cluster.

"High negative changes" in CV map are connected to urban and cultural environment, particularly to the possibility/need of public good privatization. Moreover, in SV the items relating to security and the involvement of citizens show negative effects. This evolution of the map of SV seems to confirm that a policy attentive to the natural environment but excluding the urban environment, the community and the care of public spaces, may cause negative dynamics.

Furthermore, we can notice that SV and CV show up as areas quite sensitive (with "medium negative changes") to the presence of pollution (air, water, soil) in case of policies not specifically attentive to that issue.

Both B-type scenarios (Fig. 3) show a map with homogeneous changes: in this case the individuality and the specificity of items is lost. Negative (light grey) "strong changes" and positive (medium grey) "very weak changes" are visible, but maps are far more ambiguous and hardly interpretable. This may suggest that the FCM-based model is unsuitable to the analysis of policies that are not focused on specific themes.

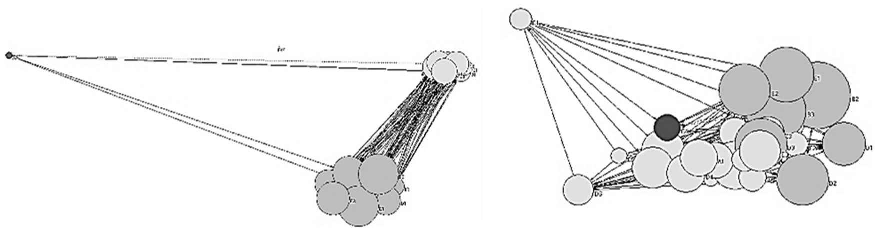

Fig. 3. Scenario B of Città Vecchia and San Vito maps according to the cluster.

4 Conclusions

The present paper aims at exploring the potentials of fuzzy cognitive maps to support decision-making in urban management processes. FCMapper software tool has been used to simulate and possibly evaluate the possible impacts of policy decisions concerning the futures of a number of areas inside the town of Taranto. The software typically carries out iteratively a simulation process, so as to foster a sort of sensitivity analysis, based on the previously collected knowledge, within the general system architecture (Borri and Camarda [10], p. 131, Fig. 1). The model works on a scenario building process embedded in the making up of the Master Plan of Taranto.

As a general outcome, the study raises interesting yet mixed results. After processing data inputs, the FCM model delivers scenario alternatives to be used in a decision support model. However, from the two scenarios depicted by the analysis, only one seems to be somehow coherent in the two neighborhoods analyzed, whereas the second one induces too much ambiguity and interpretation, thus preventing an effective support to decisions. From the substantial point of view, when compared with the outcomes of a previous experimentation in microclimate management case study [13], such results are significantly less coherent and useful as a whole. This may be due to the set of items analyzed, which was more focused on few concepts, rather than scattered throughout a large number of different problems -inherently characterizing scenario building activities.

Nevertheless, some further considerations can be carried out beyond substantial issues. As a matter of fact, the effort of raising common, informal knowledge from community interaction needs to be complemented by setting up suitable models and architectures for knowledge management. However, ICT-based integrated systems often either work as black boxes, preventing an aware management of data, or tend to synthesize the complexity of the knowledge at hand, so losing the reliability of analyses [20]. The use of FCM-based models provides interesting clues in this concern, as it is located in that area of hybrid, semi-automatic systems providing support and suggestions while leaving more control on the process. This increased reliability is typically obtained to the detriment of times and costs, which rise significantly, lowering the appeal of such models to decision-makers.

Implicitly, research perspectives on how to improve these aspects are wide and interesting, and represent a fair stimulus to enhance and enrich the overall research effort for the future.

References

1. Bossomaier, T.R.J., Green, D.G.: Complex Systems. Cambridge University Press, Cambridge (2000)
2. Schön, D.A.: The Reflexive Practitioner. Basic Books, New York (1983)
3. Friedmann, J.: Planning in the Public Domain: From Knowledge to Action. Princeton University Press, Princeton (1987)
4. Fischer, F.: Citizens, Experts, and the Environment: the Politics of Local Knowledge. Duke University Press, Durham (2000)
5. Borri, D., Camarda, D., De Liddo, A.: Envisioning environmental futures: multi-agent knowledge generation, frame problem, cognitive mapping. In: Luo, Y. (ed.) CDVE 2004. LNCS, vol. 3190, pp. 230–237. Springer, Heidelberg (2004)
6. Sawyer, R.K.: Social Emergence: Societies as Complex Systems. Cambridge University Press, Cambridge (2005)
7. Wierzbicki, A., Makowski, M., Wessels, J.: Model-Based Decision Support Methodology with Environmental Applications. Kluwer Academic Publishers, Dordrecht (2000)
8. Faludi, A.: A Decision-centred View of Environmental Planning. Pergamon, Oxford (1987)

9. Borri, D., Camarda, D.: Visualizing space-based interactions among distributed agents: environmental planning at the inner-city scale. In: Luo, Y. (ed.) CDVE 2006. LNCS, vol. 4101, pp. 182–191. Springer, Heidelberg (2006)
10. Borri, D., Camarda, D.: Planning for the environmental quality of urban microclimate: a multiagent-based approach. In: Luo, Y. (ed.) CDVE 2011. LNCS, vol. 6874, pp. 129–136. Springer, Heidelberg (2011)
11. Ozesmi, U., Ozesmi, S.L.: Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecol. Model. **176**(1–2), 43–64 (2004)
12. Giordano, R., D'Agostino, D., Apollonio, C., Lamaddalena, N., Vurro, M.: Bayesian belief network to support conflict analysis for groundwater protection: the case of the Apulia region. J. Environ. Manage. **115**, 136–146 (2013)
13. Borri, D., Camarda, D., Pluchinotta, I.: Planning for the microclimate of urban spaces: notes from a multi-agent approach. In: Luo, Yuhua (ed.) CDVE 2014. LNCS, vol. 8683, pp. 179–182. Springer, Heidelberg (2014)
14. Borri, D., Camarda, D., Pluchinotta, I.: Planning urban microclimate through multiagent modelling: a cognitive mapping approach. In: Luo, Y. (ed.) CDVE 2013. LNCS, vol. 8091, pp. 169–176. Springer, Heidelberg (2013)
15. Camarda, D., Rotondo, F., Selicato, F.: Strategies for dealing with urban shrinkage: issues and scenarios in Taranto. Eur. Plan. Stud. **23**(1), 126–146 (2014)
16. Ozesmi, U., Ozesmi, S.: A participatory approach to ecosystem conservation: fuzzy cognitive maps and stakeholder group analysis in Uluabat Lake, Turkey. Environ. Manage. **31**(4), 518–531 (2003)
17. Kosko, B.: Fuzzy cognitive maps. Int. J. Man-Mach. Stud. **24**(1), 65–75 (1986)
18. Papageorgiou, E., Kontogianni, A.: Using fuzzy cognitive mapping in environmental decision making and management: a methodological primer and an application. INTECH Open Access Publisher (2012)
19. Din, M.-A., Moise, M.: A fuzzy cognitive mapping approach for housing affordability policy modeling. Latest Adv. Inf. Sci. Circuits Syst. **4**, 262–267 (2012)
20. Khakee, A., Barbanente, A., Camarda, D., Puglisi, M.: With or without? Comparative study of preparing participatory scenarios using computer-aided and traditional brainstorming. J. Future Res. **6**, 45–64 (2002)