Planning Urban Microclimate through Multiagent Modelling: A Cognitive Mapping Approach*

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Abstract. The phenomenon of Urban heat islands (UHI) is most pronounced in areas with high urbanization and complex phenomena, in which the domains of interaction between humans and the environment are not standardized. In this context, an approach fairly attentive to agents' (particularly human) behaviors represents an interesting research perspective. The paper works on analyses carried out in a case-study of public condo housing owned by the Institute of social housing (IACP) in Bari (Italy), starting from a knowledge base collected through focus-group experimental sessions. Fuzzy cognitive mapping (FCM) is particularly dealt with, and a model based on *FCMapper*® tool allows the use of local knowledge of stakeholders' analysis for ecological modelling and environmental management in a bottom-up-decision-making process. The paper follows and completes a previous work presented and discussed in CDVE 2011.

Keywords: Urban microclimate planning, Decision support system, Multiple agents, Fuzzy cognitive mapping, Behavioural knowledge.

1 Introduction

Natural human and non-human agents together increasingly characterize urban spaces and ecosystems. The complex thermodynamics of human settlements connected to complex natural-artificial systems produce high impacts on the environment. The decisions of human agents on building, air conditioning, urban materials, mobility and transportation and other spatial productions do impact microclimate pollution.

The issue of Urban heat islands (UHI) is greater in areas with high urbanization and complex phenomena, in which the domains of interaction between humans and the environment are not standardized. In this context, an approach toward agents' (particularly human) behaviors represents an interesting research perspective. The present study looks at human-agent typologies and operational rules to build models on the significant connections between UHIs and human activities and behaviours.

The work is carried out within the EU-financed *Ecourb* project, aimed at building up hybrid scenarios for the management of urban microclimates in the area of Bari,

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Italy. It follows a previous work presented and discussed in CDVE 2011, and tries to work out if and how agents with different roles and behaviours can affect urban microclimates while performing their single and/or collective (particularly mutually interacting) activities [1]. This suits *Ecourb* framework, concerning the identification of models to support urban environmental decisions, through the analysis of multi-agent processes and the identification of variables, parameters, indicators useful in system architectures. Indeed, a deep knowledge of cognitive/social characters is needed for an effective model of environmental behaviours and interactions.

The paper works on a case-study of public condo housing owned by the Institute of popular housing (IACP) in Bari, starting from a knowledge base collected through focus-group experimental sessions. This process aimed at formalizing the perception of energy consumption in homes and the behaviors of users toward UHIs in the management structure and systems, with a multi-agent systems approach [2][3].

This approach is framed on future studies and scenario building methodologies, trying to identify the reciprocal effects of events, beliefs and attitudes that in complex systems are only apparently unrelated [4]. It is then necessary to define the relationships between environmental behaviours and/or to examine the impacts between events or trends. For these reasons in our study we investigate on the potentials of cognitive-mapping-based tools, particularly on cross impact evaluations.

Fuzzy cognitive mapping (FCM) is particularly dealt with here, since a good number of applications have been implemented with fair interest [5][6]. In our case, a model based on FCM allows the use of local stakeholders' knowledge for ecological modelling and environmental management in a participatory management schemes. Subsequently, the FCM-based model is included in the general system architecture supporting policy decision making on urban microclimate [1]

Within this general framework, the paper will be structured as follows. After the present introduction, a second chapter will introduce the project framework beyond the study and lay out the main research issues dealt with. A subsequent chapter will describe the case study and the experimental layout, whereas brief remarks conclude the work, by discussing general results and envisioning further research perspectives.

2 A Multiple-Agent Framework

The quest for models able to support public decisionmaking on urban microclimate has received increasing attention during the last couple of decades. The awareness on global warming effects on human settlements and the uprising problem of urban heat islands are structurally informing the strategic agenda of public managers and administrators. This is not a simple task, though, as occurring for all decisions involving complex systems, particularly in the environmental domain [7]. Additionally, social issues themselves affect (and are affected by) environmental microclimate problems, inducing their own complexity essence to a complex-system context [8]. Such situation does actually occur in urban contexts, both at the social aggregate level and at the single-agent level, in different ways. From the viewpoint of knowledge management, for example, there is a consolidated aggregate approach, fairly based on regular microclimate surveys with increasingly detailed datasets. Indeed, such surveys are traditionally well available at the macro level on large regions, but more and more available also at micro level of cities and even neighbourhoods. Yet, just the micro level of attention has nowadays boosted an increasing interest to disaggregate forms of knowledge and data raising, oriented at exploring the cross-impacts between micro behaviours and climate [9][10].

In open spaces, some public funds are for example devoted to the installation of sensors in particular parts of the cities. Such surveying agents are frequently aimed at monitoring concentrated pollution as an output of human activities (transportation, industry etc.) in urban areas for safety policies. In residential buildings, on the other side, heating and conditioning systems monitor and manage temperature, humidity and the thermal comfort of human agents. Yet, disaggregate approaches allow a reverse and quite important viewpoint, shading lights on a traditionally latent although critical issue of microclimate management, that is agents' behaviours [10][11]. Starting from the mere regulation of devices by human agents, to opening windows for lighting or refreshing, to shutting doors because of other agents' noise, a number of mutual, multiple or single-agent behaviours impact on microclimate management and shows uncommon features and relations that cannot be set apart from a formal process of microclimate management.

However, the increasing awareness of an inclusive approach mirrors the awareness of its complexity as a 'wicked' intertwined problem, intrinsically hard to be surveyed, monitored and managed [12].

The answer to this managing problem is investigated in the ECOURB project through resorting to multiagent system approach [2]. In this context, a major effort is to build models based on ontologies of agent types, roles and different tasks, linked by mutual relations and formal connection rules, at different scales and aggregation levels [1]. The taxonomy of involved agents includes natural as well as artificial agents, with diverse intelligence levels and prerogatives. Consequently, they perform a number of tasks, either routinary (near/remote sensing, quantitative data transmission, numerical computing etc.) or intelligent (spatial cognition, data interpretation and exchange, analogical behaviour, coordination etc.). As a matter of facts, routinary tasks are normally modellizable by formal rules and/or algorithmic functions where relevant, as consolidated case studies and literature show [13][14]. On the contrary, cognitive and behavioural tasks often rely on qualitative features and informal languages, so implying an inherent difficulty in extracting formal functions, structures and datasets, in the quest for a manageable multiagent model [15][16][17].

Therefore, drawing features and relations out of cognitive agents' actions/ interactions toward the definition of formal functions and rules becomes a critical research issue. Machine learning is a major research area in this concern, particularly effective when languages are averagely uniform and sentences are closely structured [18]. However, real-life contexts are often based on forms of low language structuring, and there is the need of more hybrid and controllable approaches.

Accordingly, the present paper is the result of an investigation on a knowledge interaction arena, focused on the behaviours of residential agents in terms of climatic and thermal comfort. The complex interactions between human agents and between human and artificial (e.g., equipment) agents are investigated with the aim of modelling informal knowledge as a module of a more general decision support system architecture for urban microclimate policymaking. The general task of this module is to visualize possible behavioural modification outputs consequent to the modification of one or more behaviours as inputs, basing on the behavioural framework resulting from the knowledge model.

3 Description of the Case Study

Many types of ecological or environmental problems would benefit from models based on people's knowledge. This paper presents the use of a semi-qualitative tool, Fuzzy Cognitive Mapper (*FCMapper*), applied to stakeholder representation of environmental problems. FCM can be described as a qualitative model that portrays how a given system, particularly a complex system operates [5], or as a representation of a belief system in a given domain [19].

The domain of interest of the present paper is the study of impacts among events or trends originating from the variation of some elements of the system. The attempt is to evaluate related possible modifications of decisions and policies, so as to envision impact areas. This approach is useful for the analysis of informal relations and the singling out of the most desirable future visions in a model for environmental management. This is located in a context of generation of the agent's knowledge base, through the investigation of the relations among environmental behaviours. The aim of such approach is to single out actual dictionaries connected to each agent's cognitive frame and to characterize correlations among the elements of a complex system, through a relational model made up of an adjacency matrix with its related cognitive map [6].

In particular, in this case study FCM allows the singling out of relations among factors with a priority role in an agent's decisional process, as well as the examination of mutual impacts toward the recognition of useful elements of the environment-building-device-users system. Such methodology makes it possible to draw out the qualitative effects of a changing action on actual elements analysed on the map.

In the present case study a focus-group interaction has been set up, with the aim of investigating visions, criticalities and strategies related to environmental themes. In particular, the first stage has been developed broadly using a *future workshop* approach, with one preparatory and three operational stages (*critic*, *fantasy*, *implementation*, see [20] and [21]). Each stage has been carried out for the building scale, the neighbourhood scale and the city scale levels, involving a number of tenants of social housing units (IACP) in the city of Bari. The aim of the workshop was to collect a knowledge base toward the formalization of personal perceptions and behaviours on energy use and management, as well as on UHI and microclimate management. The workshop was further aimed at achieving more information of tenants with both indoor and outdoor environments, by using a multi-agent cooperation approach [2]. More details on this modelling activity are available on an earlier CDVE paper [1].

After the workshops, results were studied and organized for subsequent formalizations, and a sample was used for the aims of the present study. In particular, a cross-impact matrix was built up, filled with the results of the *fantasy* stage of the household-scale level, dealing with freely generated conceptual images of desirable features of the daily living context (building). They were “A cleaner house” (C1), “A prettier house” (C2), “More tranquillity” (C3), “A more comfortable house” (C4), “A greater house” (C5), “A brighter house” (C6), “A warmer house” (C7), “Greater balconies” (C8), “No wall humidity” (C9), “An autoclave because there isn't enough water” (C10), “Structural stability of residences” (C11), “Saving electric energy” (C12), “An elevator for disabled” (C13), “A new elevator” (C14), “A new and working main door” (C15), “Modern technology to save money” (C16).

Subsequently, images resulted have been analysed by a group of scientific researchers (considered ‘experts’, as compared to ‘non-experts’ participants, see [22]) in order to define relations among concepts in the matrix, with related impact weights. The strength of a connection between two concepts indicated the intensity of their correlation, and *FCMapper* allows the assignment of -1 (inverse), 0 (absent), 1 (direct) values to correlation.

In order to verify the potentials of the FCM approach, the outcomes of the *fantasy* stage at the household scale were used as an initial layout scenario (Scenario n.1) to be compared with further elaborated scenarios coming from the variation of some variables related to decisional alternatives (Scenarios n.2,3) . In particular, the first example analyses the impacts coming from a well focused and aware strategy, whereas the second example deals with a strategy characterized by high levels of ambiguity and generality. The comparison allowed an ad-hoc verification of the decision support model, through emphasizing an convergence and coherence in the first case, and a substantial lack of convergence in the second case. The tool carries out comparisons starting from the relations among items identified in the initial scenario. Subsequently, through a graph partition, it allows the singling out of sectoral elements involved in positive or negative changes (from 2 = high positive change to 9 = very low neg. change; 10 = no change).

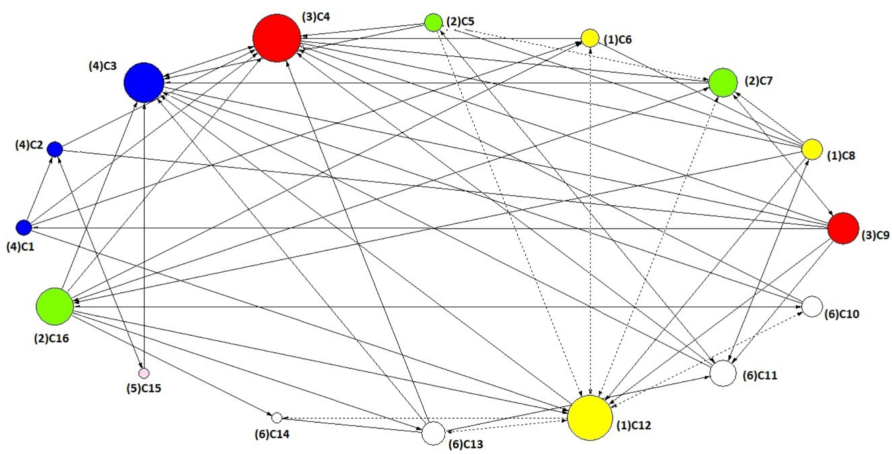

Fig. 1. Fuzzy map with graph partitions of scenario n.2, by *FCMapper* (2D projection of the 3D map: size of centers related to the values of concept centrality in adjacency matrix)

The first example hypothesizes a policy decision toward encouraging energy savings for the improvement of indoor microclimates. This is achieved through non-technological environmental and structural solutions, such as, e.g., larger balcony and the like (Fig. 1). The derived graph partitions shows that scenario n.2 includes positive as well as negative change impacts, with similar items are aggregated in colour and/or spatial location.

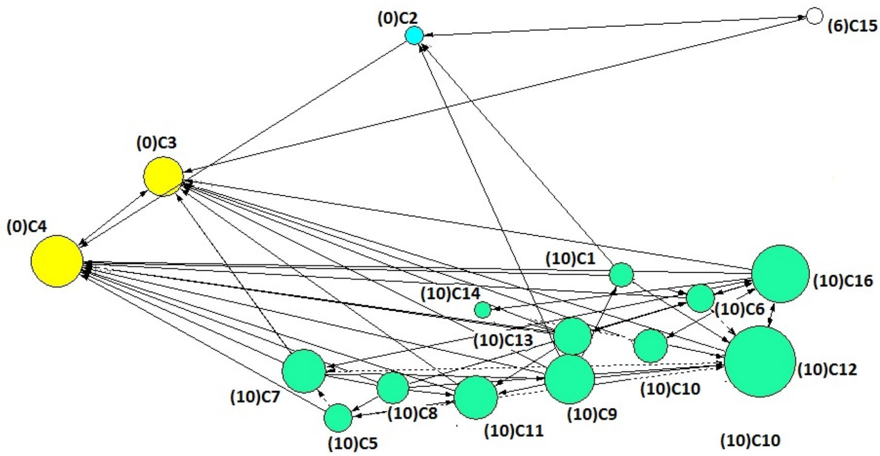

Fig. 2. Fuzzy map with graph partitions of scenario n.3, by *FCMapper* (two-dimensional projection of the 3D map, optimized through showing cluster mapping only).

In the second example the initial scenario has been compared to the more general scenario n.3. This example hypothesizes a policy decisions enhancing unfocused, general issues such as "more tranquility", "more comfort", "a prettier building". The resulted graph partition shows that there are no clustering elements, whereas primary items are affected by no change (value = 10) (Fig. 2).

As a whole, the above experimentation is aiming at better explaining the proposed methodology. Through fuzzy graph mapping it allows an easy identification of elements deriving from human agents' perceptions toward indoor microclimate. This makes such knowledge accessible and easily comprehensible by decision makers and agents themselves, so simplifying the discussion and consequent analysis and decisions.

4 Final Discussion Notes

The main aim of this paper is to show the potentials of using FCM-based formal models to manage complex knowledge involved in multi-agent behaviours within a system architecture supporting decisions affecting urban microclimate. Human/artificial as well as human/human agents interacting behaviours in indoor spaces have been investigated with a social science (focus-group-based) approach and subsequently modelled by using a cognitive mapping approach.

The *FCMapper* tool allowed the setting up of a simulation framework oriented to single out possible areas impacted by selected policy decisions on urban microclimate. Through an iterated simulation process, the sensitivity analysis carried out by *FCMapper* is supposed to integrate formal data coming from the general system architecture previously defined (see [1], p.131, figure 1) toward the definition of cooperative policy scenarios of UHI management –a pretty novel achievement compared to [1]. In fact, the fairly interesting result is that the approach allows the inclusion of informal, qualitative, behavioural ontologies in the typically formal models of quantitative knowledge management of climate decision support systems.

Of course, the experimentations are affected by initial and ongoing simplifications that could not drive to formal rules. It is significant in this context that the cooperative experiments involved a quite low number of stakeholders both in the item generation and evaluating phases, so generating mainly raw visions and cooperative evaluations. Additionally, visions generated by cooperating stakeholders were not free from direct references to obstacles and criticalities, so hampering free vision generations [20][21]. Also, the domain of knowledge interaction is limited to indoor behaviours, whereas a great interest is related to outdoor and borderline domains when dealing with UHI [10].

Yet this significant number of limitations appears as a preliminary price to pay to highlight the actual potentials of the *FCM* cooperative approach. Therefore, it certainly needs to be overcome, but the interesting suggestions achieved do represent a stimulus for the enhancement and enrichment of the research project in the future.

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