Specification of CPN models into MAS platform for the modelling of social policy issues: FUPOL project

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Abstract: Simulation transparency is becoming more crucial in the decision making process when quantitative computer tools are used to justify some strategies. The coloured petri net (CPN) formalism is a promising modelling approach to foster simulation transparency by means of state space traceability tools, which have been proven to be useful for modelling system dynamics with conflict patterns. E-governance is one of these areas in which the use of a multi agent system (MAS) to represent social dynamics in a certain urban context could be used to engage citizens in the design of urban policies that affects their habitat environment. In this paper a modelling methodology to represent and analyse a context-aware multi agent-based system, which tends to be highly complex is proposed. CPN models are used to specify citizen's preferences and affinities in front of an urban contextual change, while MAS is used to evaluate the social dynamics by translating the CPN semantic rules into agent's rules in NetLogo.

Keywords: transparency; coloured petri nets; CPNs; state space; multi agent system; MAS simulation; e-participation; FUPOL.

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1 Introduction

ICT research for e-governance focuses on the development of advanced tools for policy modelling, prediction of policy impacts, development of new governance models and collaborative solving of complex societal problems. The term e-participation is quite new and it is widely used in e-governance and e-democracy programmes. E-participation in urban decision-making means the use of ICT for enabling and strengthening citizen participation in democratic decision-making processes. The use of ICT in e-participation process consists of motivation and engagement of a large number of citizens through diverse modes of technical and communicative skills to ensure broader participation in the policy process, real-time qualitative and accessible information, transparent and accountable governance (Islam, 2008).

There are several initiatives to define a new governance model which actively engages and empowers citizens in public service delivery decision making process by means of new ICT-based platforms to create, share and foster a mutual learning approach between citizens themselves and between citizens and public administrations in the design of public policies. Some of the most relevant research platforms to support policy makers in their decision-making process enabling them to set up policies are:

- Cockpit (http://www.cockpit-project.eu/)
- WeGov (http://www.wegov-project.eu/)
- PositiveSpaces (http://www.positivespaces.eu/)
- Padgets (http://www.padgets.eu/).

It should be considered that although the development of a city should be driven by its inhabitants, citizens have participated rarely in the decision making process due to, among other problems, the complexity in the interrelationship between the different urban policy domains (OECD, 2001).

Digital simulation techniques could play an important role to engage citizens in the policy decision making process, however, the use of overly ambitious computer simulation models has been up to now very limited and restricted to certain types of planning (Almeida and Gleriani, 2005; Johnson and Heinz, 2007; Lauf et al., 2007; Moghaddam and Samadzadegan, 2009; Silva, 2008; Verburg et al., 2006; White, 1983), e.g., delivering regularly forecasts for transportation capacity planning, in which scientific knowledge has been used to legitimise political arguments.

Most urban simulation models do not take into account the demands and skills of the multiple and heterogeneous users of a model in practice. There exist fears, expectations and prejudices among the practitioners against the models: quantitative models are monsters and do not capture the social aspects in an adequate way. A lack of credibility in the models is reported due to non-scientific actors being not aware of the uncertainty inherent in such models. As a result, mistrust or communication problems can be found generally between scientists and actors.

Some approaches that try to increase the use of simulation techniques in the urban planning decision making process are:

- IMPACT (http://www.policy-impact.eu/)
- OCOPOMO (http://www.ocopomo.eu/)
- UrbanSim (http://www.urbansim.org)
- APPSIM (http://www.jinjingli.com/microsimulation/appsim).

In contrast to traditional urban modelling methodologies, the proposed causal modelling approach in FUPOL takes into consideration that actors have different skills and pre-knowledge of the complex urban system. By incorporating users' heterogeneity in non-scientific knowledge (subjective values), interests and preferences (Gerometta et al., 2005), FUPOL modelling approach contributes to overcome one of the main shortages of present policy models: citizen e-participation.

By means of a multi agent system (MAS) simulation platform, FUPOL models allow citizens to test the benefits and shortages of different proposed urban policies and check new policies according to their own beliefs.

Figure 1 Main FUPOL simulation tools (see online version for colours)

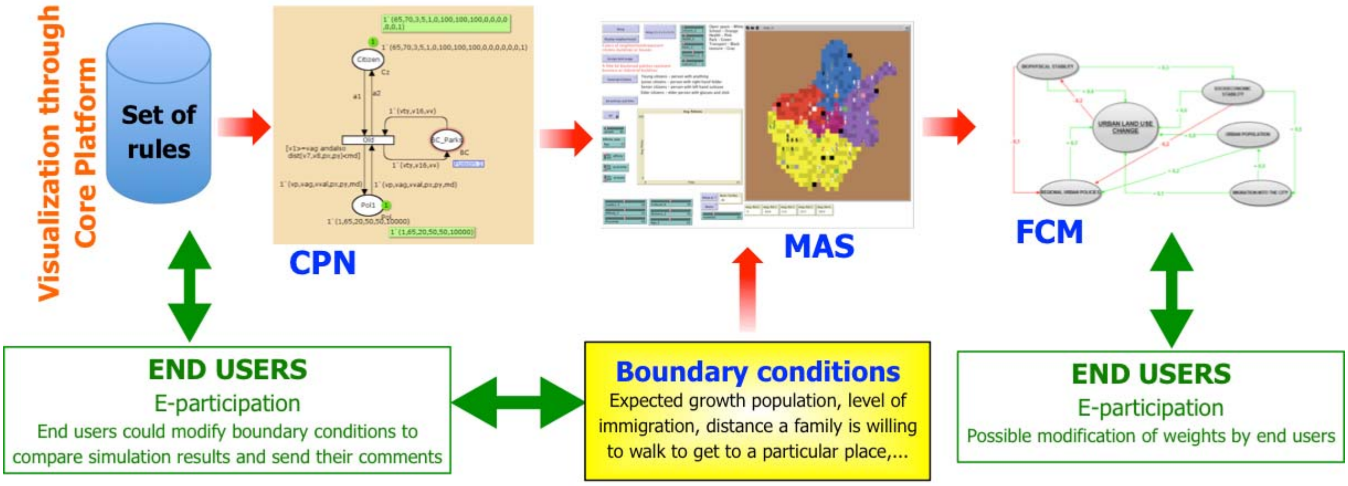


Figure 1 illustrates the selected tools to model the different urban policy domains by properly integrating fuzzy cognitive maps (FCM) (Kosko, 1986; Özesmi and Özesmi, 2003) and coloured petri nets (CPNs) (Moore and Gupta, 1996; Jensen, 1997; Christensen et al., 2001; Mujica and Piera, 2011) under a MAS environment, which presents great advantages in order to analyse social systems (North and Macal, 2007).

The urban policy models consist of a library with citizens' affinities together with urban areas defined by social activities (constraints and facilities). Citizen affinities can be categorised considering the particular attributes of each person, such as their age, the amount of kids, the incomes and sex among others. All these citizen affinities are described as a set of informal rules that can be easily checked/maintained/modified by different end-users.

The library of rules (citizen affinities together with social activities) is automatically translated to CPN formalism (Mujica and Piera, 2012) for a causal-based state space analysis. Graphical information system (GIS) information with micro population information is used to create citizen and patches agents in NetLogo. Agent behavioural rules are formalised using the CPN affinity approach.

As a result of the simulation, numerical data generated is processed under a data mining approach (ANFIS) to automatically generate the main causal weighted relationships for a certain urban policy, using fuzzy cognitive maps for end users macro level experiments.

2 Multi agent systems

MASs have been applied in various fields related to human sciences, such as political sciences, economics, and social sciences (Erel, 2012; Wilensky, 1999), in which an agent can be seen as an actor that has the power of 'agency'. The concept of agency is paramount since it extends beyond a single human being to organisations and social systems, where some have 'agency' power with the ability to make decisions, while others do not have such power. These agents communicate, collaborate and negotiate among each other in order to meet their design objectives.

During the developing phase of MAS, it is necessary to simulate the system feasibility before the formal implementation. One way to achieve this objective is to develop a model to represent the behaviours of the MAS and then to simulate the model performance. In practice, a lot of time might be spent on modelling MAS behaviours while the resulting process models are typically still not compatible with the original system due to the lack of information about actual behaviours of the MAS. To avoid this difficulty, CPN models can be used to describe agents' behaviour and predict the performance by means of state space analysis tools.

In FUPOL several MAS platforms has been analysed (Railsback et al., 2005), among them NetLogo has been chosen as a simulation environment (Damaceanu, 2011).

NetLogo is an agent-based model programming environment built on the programming language JAVA and authored by Uri Wilensky. Due to its flexibility it is well suited to fully integrate the semantic rules present in CPN using the code available in the procedures window of NetLogo. The implementation of CPN semantic rules allow to govern the agents that interact within the environment in a more transparent way which is useful to understand the emergent dynamics caused by the agent interaction.

2.1 Agents in NetLogo

The NetLogo environment is made up of agents. Agents are beings that can follow instructions. There are four types of agents:

- Turtles: Turtles are agents that move around the NetLogo environment.
- Patches: The world is two dimensional and is divided up into a grid of patches. Each patch is a square piece of 'ground' over which turtles can move.

- Links: Links are agents that connect two turtles. Links can be directed (from one turtle to another turtle) or undirected (one turtle with another turtle).
- The observer: The observer does not have a location – one can imagine it as looking out over the world of turtles, links and patches. Generally speaking the observer is the developer and can test instructions over the environment developed in order to verify the behaviour of the different agents.

3 Coloured petri nets

CPNs is a simple yet powerful modelling formalism, which allows to properly modelling discrete-event dynamic systems that present a concurrent, asynchronous and parallel behaviour (Moore and Gupta, 1996; Jensen, 1997; Christensen et al., 2001). CPN can be graphically represented as a bipartite graph, which is composed of two types of nodes: the place nodes and the transition nodes. Place nodes are commonly used to model system resources or logic conditions, and transition nodes are associated to activities of the real system. The entities that flow in the model are known as tokens and they have attributes known as colours. The use of colours allows modelling not only the dynamic behaviour of systems but also the information flow, which is a key attribute in decision making (Mujica and Piera, 2011).

The formalism can be graphically represented by a bipartite graph where the place nodes are represented by circles and the transition nodes by rectangles or solid lines. Figure 2 illustrates a graphical representation of a CPN model.

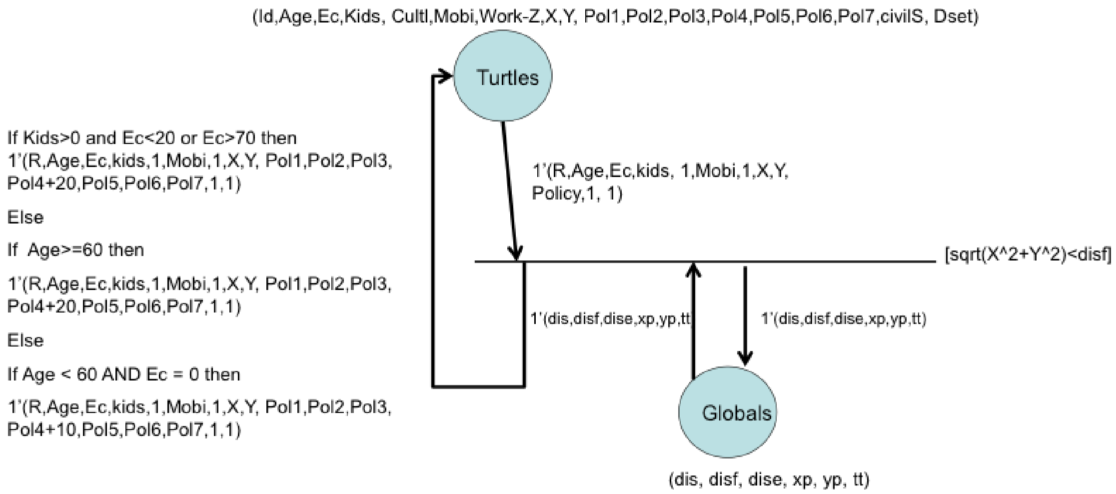
4 CPN rules and the code in MAS

Agent behaviour will be codified from a structural point of view by means of procedures each one with a series of commands. A procedure in a computer program is a specific series of commands that are executed in a precise manner in order to produce a desired outcome. However, it is important to be careful to make a distinction between the actual behaviour of the agent and the mechanics of the MAS procedure that is used to define the behaviour. The purpose of much of the procedural commands is to manipulate internal variables including global variables and the agent's own variables. The latter reflects the state of the agent and can be represented as points in an n-dimensional space.

The formal specification of a citizen's affinities into CPNs allows the verification of the agent behaviour considering its interaction with others agents. CPN models would be converted to a finite state machine by organising the states into the 'sense-think-act' mode of operation.

It is worthwhile to note that the proposed approach is not restricted to do the conversion in this particular way, since sometimes the states and transitions must be organised in whatever manner is decided during the modelling phase. In FUPOL, the states and transitions in the CPN model are organised to reflect the type of action (sensing, thinking or acting) the agent is about to perform during the next transition out of the state. Also, regardless of the path chosen, the order that the states are traversed is always a sensing state followed by a thinking state then an acting state. This is then followed by another sensing state and so on. For example, the agent's behaviour starts by a sensing state, there is only one transition out of this state, and the particular sense being used will depend on the transitions formalised in CPN. The agent then moves onto a thinking state that considers the information it has received from what it has just sensed. The thinking action the agent performs is to rank their affinity to the policies under study, according to the agent context and the inner preferences. Note that doing nothing is considered an action. The agent will then move to a new sensing state that involves the sensing action of looking for new affinities with the agent's context. It will repeatedly loop through the acting state and back to the start.

Figure 2 CPN model of land use participation (see online version for colours)



The 'sense-think-act' method of operation can show some limitations when applied to modelling cognitive behaviour, and an alternative approach embracing embodied, situated cognition can also be implemented in CPN if needed. The question concerning how to implement such an approach since it effectively entails sensing, thinking and acting all occurring at the same time, i.e., concurrently, rather than sequentially, is analysed and solved through the CPN state space analysis tools, since CPN formalism provides formal qualitative and quantitative analysis of concurrent processes. In case the policy user case would require a concurrent MAS approach, and the concurrency state space analysis would reveal a sensitivity in the results, the right control procedures in a flow control Agent will be implemented.

4.1 Agent interaction specification

Agent behaviour is represented by the actions the agent performs which results in some change to its own state, to the state of other agents or to the state of the environment. The type of change that occurs represents the outcome of the behaviour.

Agent-based modelling concerns itself with modelling agent relationships and agent interactions as much as it does modelling agents and agent behaviours. One of the primary issues of modelling agent interactions using CPN are specifying who is, or could be, connected to who, and the dynamics governing the mechanisms of the interactions. For example, an agent-based model of an open space urban policy would include mechanisms that specify who connects to who, why, how and when.

In North and Macal (2007) a set of common topologies used in agent-based models for representing social agent interaction are presented, mainly:

- a spatial model (also known as soup) in which agents have no location and the model has no spatial representation
- cellular automata in which agent interact from cell to cell on a grid
- Euclidean space model, agents roam in 2D, 3D or higher dimensional spaces
- GIS topology, agents interact over a realistic geo-spatial landscape
- networks allow an agent's neighbourhood to be defined more generally and sometimes more accurately.

By considering that agents only interact at any given time with a limited number of other agents out of all the agents in the population, the affinity and proximity attributes defined in the CPN model will determine each citizen's neighbourhood and thereby will limit the interaction to the small number of agents that are considered in that neighbourhood. The network topology allows agents to be linked on the basis of relationships other than proximity. In FUPOL dynamic networks are used to describe the affinity and proximity interactions required in urban policy modelling, which are formalised in CPN. This approach ensures the traceability of the cause and effect for transparency purposes when analysing simulation results.

4.2 Time specification

Usually, agents enter or leave a system by participating in a role-management protocol, which prescribes the ways for applying for membership, withdrawing from a system, and so on. The specification of a role-management protocol is quite particular to each urban policy domain, so different CPN models must be implemented for each specific domain. Thus, the creation of agents in a green park design model is mainly driving at the initialisation of the simulation from the GIS data and the scope initial specification, while the creation of agents in an industry-economical model is quite dynamic according to the evolution of the interaction between the agents to deal with a trade-off between the key performance indicators modelled.

Time specifications of laws that allow agents to achieve their goals at run-time are also specified in CPN formalism.

4.3 Flow model specification

Most MAS allows the definition of an observer agent which provides overall model management. There is typically only a single observer per process. The observer implementation simplifies model initialisation by automatically creating a shared context and the projections appropriate for the simulation.

A general and well accepted approach to manage the flow of interaction between agents is to empower each agent to decide the right interactions to deal with at any time. However, for transparency purposes, despite this approach is well supported by a procedural flowchart in which at every time advancement of the simulation, or \tick, each agent will execute his own step method, the overall flow of each policy user case model, together with the information flow and agent interaction are specified under the CPN formalism. Thus, state space analysis tools (i.e., reachability tree) allow the formal analysis of the different agent interactions and the new states that can be reached. This quantitative analysis is used to implement in the observer agent certain policy-related rules to avoid non-desired interactions, which could lead to erroneous simulation results.

The CPN specification will play an engine role by:

1 integrating different information flows (such as citizens characteristics, biophysical environment and policy information) from the different agents into the decision-making

2 scheduling the agent's decision-making processes and subsequent actions

3 governing the behaviour of the different types of agents.

5 Case study: green park area design

The simulation objective for a green park design in Zagreb is to provide the best solution for the facilities that would be included in the 30,000 m^2 of green area situated near the Autism Centre. The design must satisfy most of the potential users' demands and must encourage interactions between autism people and non-autism users, while avoiding possible conflicts between them. At the same time, possible conflicts between all kinds of users must be avoided. For example, nobody likes to have dogs around kids while these are playing in a playground.

Figure 3 illustrates some conceptual designs under study in which the green park will be placed.

The CPN specification of citizen's behaviour requires colours to be defined. These colours are used as part of the different agents with the purpose of tracking down the information flow that takes place when a decision is performed by the agents.

Table 1 illustrates the kind of attributes and colours that are used for the green park design CPN model.

Figure 3 Conceptual green park designs under study (see online version for colours)

Table 1 Colour attributes of the open space example

Colour	*Meaning*
Age	Age of the citizen: most urban policies are highly dependent of the population age of citizens that will be affected. Age diversity usually is a problem when trying to devise the benefits of a certain urban policy.
Ec	Economical incomes rate: It takes a value between 0% and 100%. 0% means unemployed without subsistence. 100% means a well standing economical position. This information is highly relevant to simulate the economic impact of urban policies.
Kids	Amount of kids bellow 18 years olds: this information is important to evaluate the social impact of urban policies.
CultL	Cultural level: A value between 1 (no studies) until 5 (PhD level). This information is useful not only to evaluate the impact of a policy, but also to describe how his affinities can affect or can be influenced by their neighbourhood's opinions.
Mob	Mobility: Describes the preferences of the urban population to access places (working, leisure, shopping, etc.). It is parameterised using 5 values: 1 – Car, 2 – Public urban transport (bus/subway), 3 – Public regional transport (train/buses), 4 – alternative transport means (cycle/by food).
Work	Work place: A discrete value indicating the amount of zones to travel to reach its working company. In this example it is used binary information indicating if the work place is in the area of the study.

The affinities of the citizens for the different activities that can take place in the green area are specified in CPN by means of transitions. In Table 2, the main activities considered in the CPN model are mentioned.

Table 2 Some green park citizen's activities

ID	*Activity*	*ID*	*Activity*
A1	Cycling	A2	Exercising
A4	Jogging	A5	Jumping
A7	Lying on a bench	A8	Performing street theatre
A10	Playing badminton	A11	Playing frizbee
A13	Playing with a ball	A14	Pushing a pram
A16	Roller-skating	A17	Running
A19	Sitting around a table	A20	Sitting on a bench
A22	Sitting on a bench with a pram	A23	Standing
A25	Standing with a pram	A26	Stopping/ talking-walking a dog
A28	Walking	A29	Walking-pass through

For each activity, a transition in the CPN model is specified, formalising the different restrictions that must be satisfied by the set of agents that participate in the evaluation. All the restrictions imposed by the CPN elements (arc expressions, guards, weights) are evaluated in a single procedure that takes into account all of them in order to determine if the selected elements (agents) satisfy the correspondent restrictions. Table 3 summarises the main restrictions and rules between particular citizen's colour values and their affinities to practise the activities modelled in the green park area.

Specific citizen behavioural rules that have been formalised in CPN and later codified in a MAS platform (NetLogo) are:

- S1: Kids between three and five years of age are mostly interested on playing (i.e., swings, sandbox); however, sometimes they could prefer to sit on a bench or around a table to have some snack or even to have lunch.
- S2: Kids between 6 and 12 years of age are also mostly interested on playing (i.e., playing ball); however, their plays are quite different than kids between 3 and 5.
- S3: Young people between 13 and 19 years should have other concerns and responsibilities. Some of them can be really interested in sports (individual and collective), and they can be responsible of a dog. And preferences can vary between males and females. However, if they do not like sports, males and females share preferences (it will implies to include them in the same rule), and these are sitting (could be on the grass, around a table, on a bench,...) or some pair situations like walking or sitting together. Due to the fact they can move around by themselves, walking pass through the park can be also one of their activities. Regarding sports, they have different preferences that can be summarised using statistics.

One of the main advantages of analysing the rule-based model using CPN formalism, is that the state space of the system can be computed without considering either particular time constraints (time events), or particular stochastic factor constraints. Thus, the full state space of the system can be computed providing all the event sequences that could occur in the real system together with the evolution of the system (state variables) from an initial state to the different final states.

Table 3 Citizen affinities

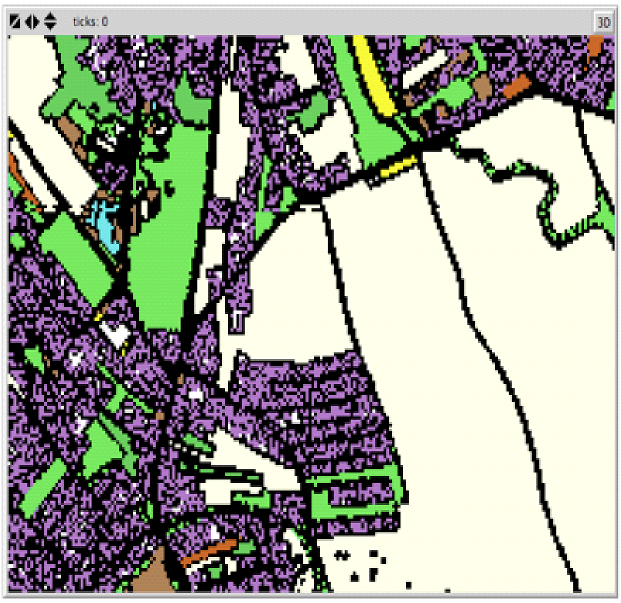
Main profile	*Companion*		*Activities and percentages*				*Time frames*				
							9:00–12:00	*12:00–15:00*	*15:00–17:00*	*17:00–20:00*	*20:00–00:00*
P2	ID mother	ID father	A5	A7	A8+A9				W	W	
	ID grandma	ID grandpa	50%	30%	20%		WE	WE		WE	
P3	ID mother	ID father	A8 + A9 + A10 + A11		A13	A12 + A15			W	W	
	ID grandma	ID grandpa	60%		20%	20%	WE	WE		WE	
P4	ID mother	ID father	15	16	A8 + A9 + A10 + A11					W	
	ID grandma	ID grandpa	40%	40%	20%		WE	WE			

In case a feasible final state is never reached (i.e., for example the swings zone in a green park is never used), it is possible to check why the conditions for an event are not satisfied and modify the rules (i.e., the transitions) or add new rules (i.e., new transitions) to achieve an acceptable representation of the system.

The MAS model will also be validated using statistical analysis tools (hypothesis test and confidence interval computations among others) comparing the field data observed in similar scenarios (i.e., other green parks in Zagreb) with the data generated by the simulator.

In order to foster the use of simulation as a neutral tool for supporting e-participation end users are allowed to change the boundary conditions. Figure 4 illustrate a macro level description of the context conditions of a certain experiment in which end-user specified the preservation of the agricultural area near the autism centre.

Figure 4 Visualisation of scenario boundary conditions (see online version for colours)



5 Conclusions

Under the framework of the FUPOL project one challenging task is the policy modelling and analysis. The proposed methodology has been performed through a novel approach which models the different actors in a policy process as agents whose behaviour is governed by a causal modelling developed in CPNs. The translation of the CPN models into a MAS platform allows a novel way of understanding the causal relationships that are behind decision making in society. With the use of CPN it is possible to implement the causal relationships that govern the agent behaviour in such a way that more transparency is achieved during the evaluation of a particular policy. The approach presented will be used during the development of a simulation module within the FUPOL framework that will allow the participation of real citizens through social networks to determine the parameters of some characteristics of the simulation model (boundary conditions). With the previous approach it is expected that more transparency and e-participation will be gained for the common population within a city, region or community.

Future work will be the deployment of the MAS models into a cloud computing platform in which the scale factors of real scenarios will increase the amount of relationships between agents and will influence the simulation results.

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