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Complexity, Governance and the Smart City

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1 ABSTRACT

The city is today object of scientific interest around the concept of environmental complexity. Its multiformity is an element of richness on which cities base opportunities and raison d'être, thus making it necessary their protection and enhancement, through administrative and managerial actions able to replicate rather than reduce this complex articulation. Yet the inclusive and diffuse management of the vital characters of a city includes explicit or tacit agent/environment relationships. Technology becomes critical support towards intelligent systems for structuring the problems posed by the intricacy, fuzziness and dynamical uncertainty of complex environments -particularly urban settlements. Urban organization becomes a smart city by overcoming prejudices that evoke presumed enhancing mechanisms induced by diffused infrastructuring per se. The cognitive management of the characters and features involved in the formation and organization of the smart city certainly needs adequate architectures, homotetically related to such complexity. An ontology-based approach is proposed here, as an opportunity for analysing and managing this multimensional cognitive assortment, looking for suitable formalization models beyond reductionist smart city commonplaces.

Keywords: urban complexity, smart city, knowledge management, agent-based modelling, ontology

2 INTRODUCTION

Urban contexts are today object of scientific interest around the concept of environmental complexity, due to their inherent, genetic complexity of settling environments and complementary relations – i.e., rural, mountain, marine and so on. Essential constituents of the city are typically (although not only) human agents, proponents or co-authors of a complex stratification of physical artifacts but also of social and behavioral constructions and transformations.

This multiformity is an element of richness on which cities base opportunities and raison d'être.This suggests the need of their protection and enhancement, through administrative and managerial actions able to replicate rather than reduce this complex articulation. Today we increasingly deal with models of distributed governance, rather than a top-down centralized government, so that the management of the values and needs of individuals or small groups may take place in a focused and self-determined manner, in the name of a harmonic ant operational efficiency of the urban system as a whole (Wagenaar & Hajer 2003; Bai et al. 2010; Camarda 2010). Inspirations are for example represented by the few diffused village-based settlement systems, which survive in the poorest and most inaccessible places on the planet, keeping the government of their native resources through family and/or tribal autonomous administrations whose dense horizontal interconnections are loosely based on trust and habits, but vertical ones are often of mere passive acceptance (or rejection) of rigidly top-down rules and directives without operational feedback (Cleaver & Toner 2006; Torregrosa et al. 2017). The sometimes extraordinary difference of needs and expectations in the cities, today often accentuated by their increasing ethnic differentiation, seems to transfer this characterization of refined but complex bonds even into urban contexts.

Yet the inclusive and diffuse management of the vital characters of a city includes explicit or tacit agent/environment relationships, deliberate or unconscious, uncertain, changeable, virtuous or subtle but largely ineludible for the development of urban communities. Connection is a keyword in environmental governance, involving biotic or abiotic, human or artificial or hybrid, routinary or intelligent, single or aggregated agents through horizontal/peer interactions or vertical/hierarchical or hybridly multiscalar dynamics (Batty 2007;Camarda 2012).

Just in this context technology becomes critical support towards intelligent systems for structuring the problems posed by the intricacy, fuzziness and dynamical uncertainty of complex environments -particularly urban settlements. Urban organization becomes a smart city by overcoming prejudices that evoke presumed enhancing mechanisms induced by diffused infrastructuring per se. Smart city goes beyond an urban hyper-interconnection and technologization regardless of the improvement of its thorough life, leaving out multiple and multiform aspects and agents, social dynamics because they escape simple and deterministic characterizations. Instead, smart city means managing this complexity, through multi-agent knowledge approaches, attention to features and informal relationships, remembering and managing possible, probable emerging properties beyond sums and juxtapositions. Smart city intelligently links times, spaces and agents through geographical and physical relationships but also emotional, creative, informal trusts. In this context, smart city is the city's ability to exist, maintain itself, progress as an 'agency' autonomously but intimately intelligently linked.

In this consciously complex approach, the cognitive management of the characters and features involved in the formation and organization of the smart city certainly needs adequate architectures. However, they need to be based on cognitive models that are not reticent but homotetically related to such complexity. Very recently, an ontology-based approach has emerged as an intriguing opportunity for analysis and understanding of this multimensional cognitive assortment, as well as a suitable formalization model behind smart city management architectures (Borri et al. 2016).

To this issue is dedicated the present research, with theoretical as well as operational reflections carried out with a knowledge-in-action approach. After the introduction, section 3 draws out a concise background of the smart-city conceptualization. Then a section on materials and methods follows, emphasizing some of the issued connected with a complex smart city modelling. Section 5 discusses the potentials of knowledge modelling, followed by a concluding chapter where brief final remarks are drawn out.

3 CONCEPTUAL BACKGROUND

The dawn of the tumultuous rise of city 'smartedness' brings us back to the first structural conceptualizations of the 'wired city' of the 1980s (Castells 1984, Hanson and Council 1984, Dutton et al. 1987). First reflections focused on the potentials of computer networks in the management of the immaterial infrastructures of the city. In essence, the new frontiers offered by innovations in digital and informatic technology envisioned scenarios for the improvement of public services and (particularly communication) infrastructures, to increase the wellbeing of citizens. The enthusiasm was accompanied by some skepticism towards the actual impact of this interconnected vision on cities' real economy, welfare, daily livability. However, the subsequent diffusion of the internet during the 1990s progressively clarified the enormous potential hidden behind the first intuitions on interconnection, at a global level (Sardar and Ravetz 1996).

Just the global level represented the most tangible and immediate perspective of the impacts related to the diffusion of communication and service interconnections. Small or large realities could indifferently rise to the international spotlight through simple computational agents, a previously unexpected horizon. Since then, the perspective has been continuously extending and consolidating, especially with the explosion of wireless connections in the late 1990s and early 2000s. An emblematic example of the development range induced by this explosion was the rapid escalation in the use of cellular phones and networks in developing Countries. To be precise, this diffusion gave rise to new communication processes between people and social groups all over the world. Yet somehow in developing Countries it has strengthened expectations and activated information processes, perhaps previously prepared by the television networks, thus creating new informative independence perspectives for agents. Therefore, they became capable of boosting new socializing, aggregative and, in many cases, right-claiming attitudes, even on a large scale (Howard and Hussain 2013, Tarant 2017).

In general, at the global level, new connection and communication technologies have induced many changes, even on individual lifestyles. They have fostered and accompanied the rapid development of economic and financial ideas and initiatives, as well as often induced their equally rapid decline (Wollscheid 2012).

With the start of the 21st century, new chapters in technological innovation have been progressively experienced, linked to the use of connection networks. On the one hand, new and more sophisticated ways of managing inter-agent communication relationships have developed, up to the extraordinary diffusion of social networks with their relevant cognitive, social and behavioural impacts. On the other hand, the wide technological window of the Internet of Things (IoT) has opened. It promises extraordinary future socioeconomic evolutions, yet even now representing a qualitative breakthrough for the management and functionality of confined, especially residential environments (domotics).

As a matter of facts, today the concept of smart city seems to be placed on this rich, multifaceted, innovative, functional, connective and relational paradigm. Despite epistemological criticists, it represents not a mere dehumanized vision of an Asimovian cyber-city, but a concept resulting from a long process, evident in some of its basic characters. Yet such elements today characterizing the concept of smart city, built on laws, norms as well as on the social imaginary, need to be further investigated. In particular, it is necessary to understand the extent to which they reinforce the essence of urban sustainability and livability, also ensuring their perspectives of qualitative improvement.

The environmental, relational and cognitive complexity that characterizes the spatial domains of our cities requires actions and interactions, decisions and choices for which the knowledge factor is an essential but also extremely dynamic element (Hooijmaijers and Bright 2005). This is true at the individual scale as well as at the scale of the entire urban community. If the essence of the concept of smart city is a complex, refined support for the connective relationships between elements, agents, agencies, it is evident that the super-individual scale (the scale of the groups, of the whole community) is benefited in a crucial way.

In urban planning, for example, the question is often of building future development scenarios with proper strategies that require the structural involvement of the community. In these cases the role of agents‘ knowledge, appropriately exchanged within arenas of cognitive interaction, is essential in the identification of means, objectives and areas of implementation. However, an open and evolutionary system such as the urban ecosystem is continually subject to information flows with the outside, as well as to temporal dynamics that also significantly modify the collected knowledge ('wicked' systems) (Rittel and Webber 1973). Urban planning processes that are oriented towards pursuing effective strategic scenarios need to take into consideration changes in both the aspects and the contents of knowledge, in order to dynamically recalibrate means and objectives. In this context, the building up of architectures able to manage cognitive connections that are dynamically variable becomes increasingly important (Nishida 2000, Hooijmaijers and Bright 2005).

Should smart city debates exclude these issues, by considering just the physical infrastructuring of mainstream services, then it would not do enough justice to its intrinsic 'smartness‘, so resting on a merely routinary hyper-technologization. Yet it is, of course, a qualitative leap that is still very difficult to achieve.

In fact, unlike the simple exchange of command-&-control signals which involve simple, defined and formalized elements, a 'smart' planning architecture often refers to cognitive-level elements, typically natural and artificial agents, in a continuous, informal and dynamically changing interaction. These architectures have to manage a condition in which both the knowledge agents (or agencies) and the knowledge contents exchanged in the relational processes are characterized by high fuzziness and complexity. It is true that cognitive and relational dynamics within a closed and limited group can be effectively managed in a traditional way, i.e. vis-a-vis. Yet it is also true that the same does not hold when the group of agents is extended to a neighborhood or urban community. New problems arise in those cases, showing different forms and features, that a smart city architecture should nonetheless be able to manage, in appropriate ways.

4 MATERIALS AND METHODS

4.1 Agent-based modelling

In this framework, we should mention a stable research approach today, which tends to include space-time organizations in the construction of multi-agent structures. This is often accomplished with the aim of simulating roles, behaviors, relationships, trying to extract basic operational logic instructions for multi-agent decision support. A multi-agent system model (MAS) can contain human, but also artificial, automatic, or a hybrid mix of agents of various kinds at the same time. A modeling approach of this kind can be addressed rather easily to the management of a formal agent system. However, it also shows its great potential in the urban planning domain, allowing a significant reproduction of the ontological-phenomenological richness implicit in the complexity of the environment, thereby allowing the maintenance of the necessary knowledge for decision-making processes. Fundamental studies for multiple agent systems in the environmental field are not widespread, but the various considerations and reflections, especially in terms of social simulation, are of great interest and importance for the orientation of our research (Ferber 1999, Wooldridge 2002, Arentze and Timmermans 2006, Camarda 2010, Borri et al. 2011).

Moreover, the multi-agent modeling approach contains references to one of the structural aspects of the environmental and land management process, namely the hierarchical articulation of tasks and mutual behavior between agents. An example within a more formal context is represented by economic supply chains, in which the activities of agents on the distribution chain can vary from simple routine tasks to coordination and supervision tasks (Li et al. 2010). However, these circumstances commonly occur also in environmental, urban and regional contexts, albeit in a more complex way. In these contexts, the relationships between human and/or natural and/or artificial agents typically develop between operating levels that are often very different hierarchically. Multi-agent models are inherently able of adapting to these dimensionally complex organizational structures. In this way, they offer an important potential for supporting the management of the so-called multi-scale governance (Gertler and Wolfe 2004, Baud and Dhanalakshmi 2007).

Some essential aspects can be roughly sketched out. First of all, agents can be natural actors of environmental life (human agents, animal agents, etc.), or artificial entities created for activities of cognitively high or low levels (routine entities, such as machines or sensors). For example, in the context of human agents, a coordination activity is generally considered to be of a higher level compared to a routine operating activity. According to Ferber, a classification of agents can be operated through typological (cognitive vs. reactive agents) or behavioral (teleonomic vs. reflex behavior) criteria. The typological distinction basically concerns the representation of the world by the agent. Human, artificial, hybrid agents can be placed within this classification. In particular, urban governance systems typically show combinations of types and behaviors of agents, also subsuming institutional models of relationships that need to be implemented in a multiagent model with ad-hoc approaches (Fig. 1) (Searle 1997, Sierra et al. 2007, Ferber et al. 2009).

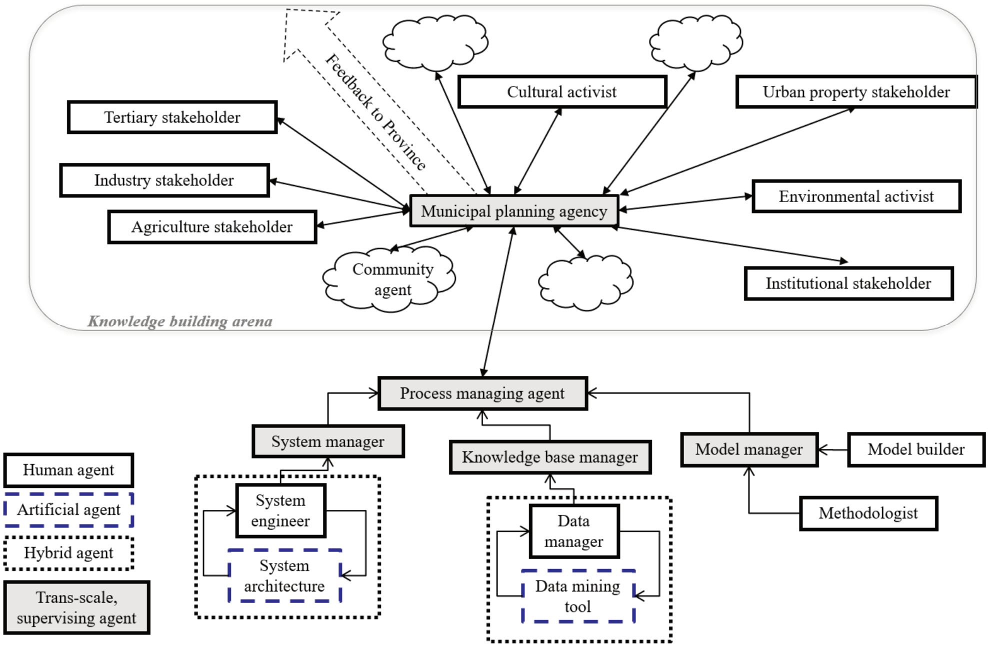

Figure 1: An example of multiagent-based layout of urban planning governance (Camarda 2012)

The environment can cover different roles in a MAS model. Intended either as an artificial computer-based infrastructure, or as a natural framework for agent interaction, the environment is an essential part of the system. Traditionally it represents a static field endowed with attitudes towards null or merely reactive external stimuli. However, the availability of reactive attitudes allows its categorization as a type of agent within a MAS model, with relations to external agents that need explicit in-depth analysis and formalization (Ferber and Muller 1996, Weyns and Holvoet 2003, Le Page et al. 2012). In particular, in the anthropic transformation processes impacting on natural resources, environmental characteristics tend to be valued and can be raised to proxies of environmental agents (Phillips and Reichart 2000). In this way we aim to achieve a more effective environmental sustainability path. The processes of urban governance are thus naturally oriented towards the support of decisions and policies within this framework, and are today increasingly interested in inclusive MAS approaches to the environment.

4.2 The formalization and modelling of relations

Interactions between agents can take place in different ways, often (but not exclusively) based on the nature of the agents. For example, human-human interactions can be realized through ICT-based tools or simply through socio-physical contacts, while human-artificial or artificial-artificial contacts typically require software-based routines. In formal terms, different relationships can be supported qualitatively and quantitatively by rules of a different nature. A typical approach for formalizing relationships between agents is often based on game theory, particularly when dealing with agents with substantially different decisional behaviors (Parsons et al. 2002, Wooldridge 2012). The implementation of formal relationships can be based on logical rules centered on causal (eg, if-then-else) connections between agents (Mohammadian 2004). In a more aggregated mode, numerical and algorithmic analysis can provide laws for the connection between agents, typically when synthetic representations of linkages are necessary (Zinkevich 2004, Stankovic 2011). As a matter of facts, methodological and rule-based approaches can be present with various mixes in real life, generating hybrid sets of formal relationships that basically reflect a reality made up of agents and hybrid relationships (Mavridis 2010, Serban et al. 2012).

4.3 The acquisition of inputs and the formalization of languages

Knowledge agents need to be supported by different technical agents, tools and sensors that are able to facilitate an appropriate and unambiguous language exchange during the interaction, which can replace knowledge inputs that are not direct (vis-a-vis). In particular, it is important to introduce the so-called enriched language in interactions, as far as possible, by integrating typical written statements with oral, schematic, graphical, gestural etc. languages. Many layout models and tools are nowadays used regularly for the implementation of this enriched language (Fig. 2) (Veloso et al. 2004, Bravo et al. 2006, Zeile et al. 2015).

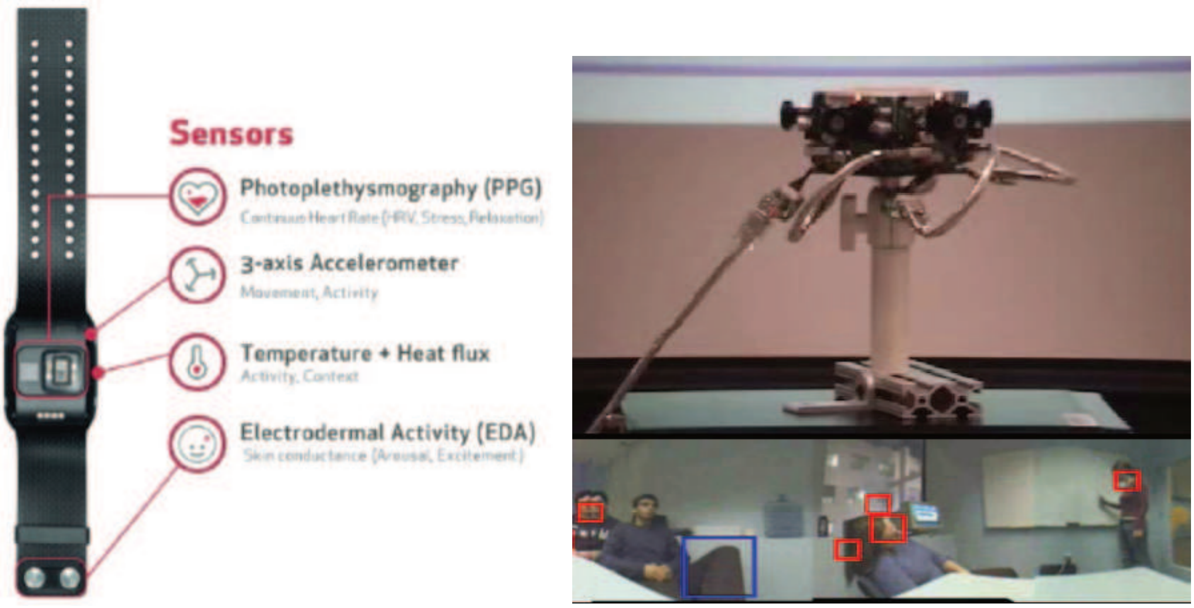

Figure 2: Tools to collect complex data toward enriched language (left: Silvennoinen 2018, p.10; right: Camarda 2010)

Languages are often derived from behavior: they express feelings, emotions, ways of being. Languages are also today expressions of sentiments that go through the 'superhighways' (Sardar and Ravetz 1996) of social networks and often capture essences, features, potentials, perspectives of a community. All these different types of language, often informal, need to be integrated into languages that are formalized, shared and able to circulate within the intangible connections of the knowledge system architecture. It is a problem of great interest for computer science, very articulate, rich and currently still open (Bateman et al. 2010).

5 DISCUSSION: MODELLING KNOWLEDGE

Following the above, the contents and formalization of knowledge is a critical point. Contents are not just words, on which we still have considerable experience, but fuzzy, uncertain conceptualizations. Enriched language is a complex language requiring similarly complex - not simplified - approaches to be managed. It is a question of extended conceptualizations, mutually connected among them, and internally composed of further primitive concepts. Words-concepts-relations represent the actual contents of such enriched knowledge, useful for cognitive interaction, as well as structural to the realization of processes for the building up of development scenarios and oriented to effective urban planning.

With the aim of maintaining and simultaneously managing this complex structure of knowledge, without simplifying it, recent studies propose formal ontological modeling (Guarino et al. 2002, Gaševic et al. 2009, Bateman, et al. 2010).

In this context, we shall remember that a city is a dynamic set of living beings and of natural or artificial entities that usefully coexist, a system in conventional technical terms. Designing and/or planning for a city (e.g. for its architecture, i.e., transforming natural entities or introducing artificial entities) is highly complex operation for the complex frame of a city system. Looking at a general definition of ontology, it can be said as "a formal specification of a shared conceptualization" (Borst 1997). The ontological analysis of an abstract city image can be performed via an applied ontology (eg., DOLCE ontology, see figures 3 and 4) (Guarino, et al. 2002), that can be assumed as being useful for planning and design management (tasks and objects) for cities.

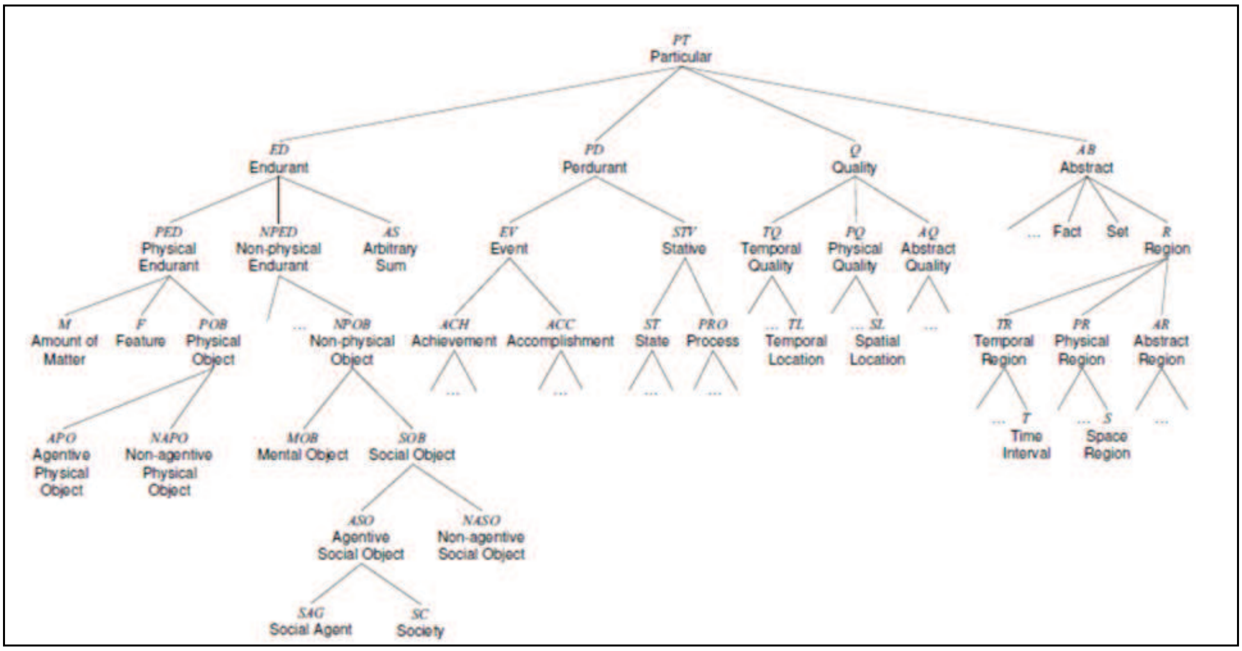

Figure 3: The taxonomy of DOLCE (Guarino, et al. 2002).

Parthood: "*x is part of y*"
$P(x, y) \rightarrow (AB(x) \vee PD(x)) \wedge (AB(y) \vee PD(y))$

Temporary Parthood: "*x is part of y during t*"
$P(x, y, t) \rightarrow (ED(x) \wedge ED(y) \wedge T(t))$

Constitution: "*x constitutes y during t*"
$K(x, y, t) \rightarrow ((ED(x) \vee PD(x)) \wedge (ED(y) \vee PD(y)) \wedge T(t))$

Participation: "*x participates in y during t*"
$PC(x, y, t) \rightarrow (ED(x) \wedge PD(y) \wedge T(t))$

Quality: "*x is a quality of y*"
$qt(x, y) \rightarrow (Q(x) \wedge (Q(y) \vee ED(y) \vee PD(y)))$

Quale: "*x is the quale of y (during t)*"
$ql(x, y) \rightarrow (TR(x) \wedge TQ(y))$
$ql(x, y, t) \rightarrow ((PR(x) \vee AR(x)) \wedge (PQ(y) \vee AQ(y)) \wedge T(t))$

Figure 4: The axioms of DOLCE (Guarino, et al. 2002).

As mentioned above, the city is increasingly conceptualized and characterized by a complex substance which has a shifting dynamic shape. There is liquidity of social relationships, being a place of individual and social rebirth and renewal with integration of different skills working together for a better life (Lynch 1960, Tversky and Hard 2009, Hillier 2012). In a smart-city context, we can contribute to a new generation of theoretical-practical knowledge-based models for city representation. The role of formal ontology is to put together different yet coherent world views: in that context, it is a specification of conceptualizations in a knowledge domain.

Before building a formal ontology, ontological analysis deals with the possibility of putting 'right' questions on a topic or problem. When ontological analysis is to be performed, the starting point is always how and why to build an ontology. Ontology is continuously applied to a number of domains, going deeper into each meaning in respect of the 'original' or 'normal' meaning given by the discipline narratives. Reality has many hidden meanings which cannot be easily ignored or bypassed in technical activities: making architectural designs or spatial plans for a city are clear examples in this concern. For example, a city definition is not neutral, depending on the perspective and the 'original' state of the definition at hand: a question must arise on how many elements are involved, what kinds of elements are involved, what kinds of languages are involved.

Ontological analysis relies on logic as a support to model reality beyond natural language (Borgo and Masolo 2010, Calafiore et al. 2017). Natural language generally uses implicit meanings and hides semantic subtleties, so that it is often not completely reliable. To overcome this problem, verbal protocols following well defined norms are needed, in order to have correct information. 'Heavy' ontologies may enable to characterize the different types of agents that are present in an action, with their behaviours (Guarino, et al. 2002, Guarino and Welty 2010).

In order to start an ontological analysis of the city we need to identify what we think about a city and retrieve definitions about it: we may find a number of definitions which are all necessary, yet no definition is exclusively right per se. In an ontology about the city it would be interesting to individuate a position for the unknown, the unpredictable, the evolving dimensions in time and space. A city is made of persons, relations, artifacts: the ontology of a city has to be a kind of polyhedral conceptual artefact. Ontological city images should be malleable and almost instantly perceptible and usable according to different and dynamic points of view. The applied ontology we are thinking here concerns a knowledge-management ontology, characterized by extension, refinement, modification, or even total replacement of knowledge parts. It should provide a kind of foundation for systematic knowledge management research and practice and a basis for designing and analyzing technological approaches to the city (Holsapple and Joshi 2004, Ballatore 2016).

Apart from what components of a taxonomy should represent the city, there is also a problem of granularity, i.e., for example, how deep to look in the city while posing the ontological analysis foundation (a kind of analogy might be recalled here, concerning the Geddesian In- and Out-Look Towers in the dawn of the XX century Edinburgh) (Geddes 1915). Also, in order to model different elements of the polyhedral concept of the city, a reflection on the abstract concept of the sense of place can be worthwhile. The ontological analysis of a city concerns a city conceptualized on the background of its tangible and intangible place, objects, elements, agents that make the constant evolving image of the city.

Given the above, a starting, bottom-up attempt of the ontological formalization of the city, carried out using the Protégé 4.0 software of Stanford University, is shown in figure 5. This is the current outcome of an ongoing project, as part of the planning process of the city of Taranto (Italy). The project is oriented to the building up of a system architecture for the continuous management of community knowledge through a reiterated cognitive interaction between citizens, mainly online. The details of this project, as well as its intermediate results, are partly published, partly forthcoming in planning journals (Borri and Camarda 2017, Camarda 2018, Pluchinotta et al. 2019). In this architecture of interconnected knowledge, the ontological approach plays a fundamental role - fig. 5 here representing only some aspects of a thorough conceptual formalization of the city.

The ontology starts from a simple conceptual tree, where the ontologies induced by Taranto experimentations are integrated (merge function) and represented through classes and subclasses, which are connected through logical properties of IS-A type. The formal ontology is written in Web Ontology Language (OWL 2.1) (Møller and Schwartzbach 2007, p.31), a markup language used to represent meanings and semantics through shared vocabularies and shared relationships between verbal terms. OWL explicit goal is to allow the processing of human-generated information through general software agents rather than simply through human agents (Lacy 2005). The space-environment ontology is therefore suitable to be

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processed by argumentative and query-based inferential engines for purposes of decision support on navigation tasks or maintenance of the space itself.

From the point of view of environmental governance, however, the involvement of a plurality of agents with multi-faceted conceptions of space still remains essential. The knowledge solicited and exchanged in real processes of group argumentation is a critical issue for building and obtaining realistic planning development scenarios for communities. Due to the the well-known knowledge/action dichotomy in decision and spatial planning, intensively discussed in the domain literature (Schön 1983, Friedmann 1987, Forester 1999), multiagent DSS architectures can suggest interesting developments in terms of cognitive and operational connection and catalyzation.

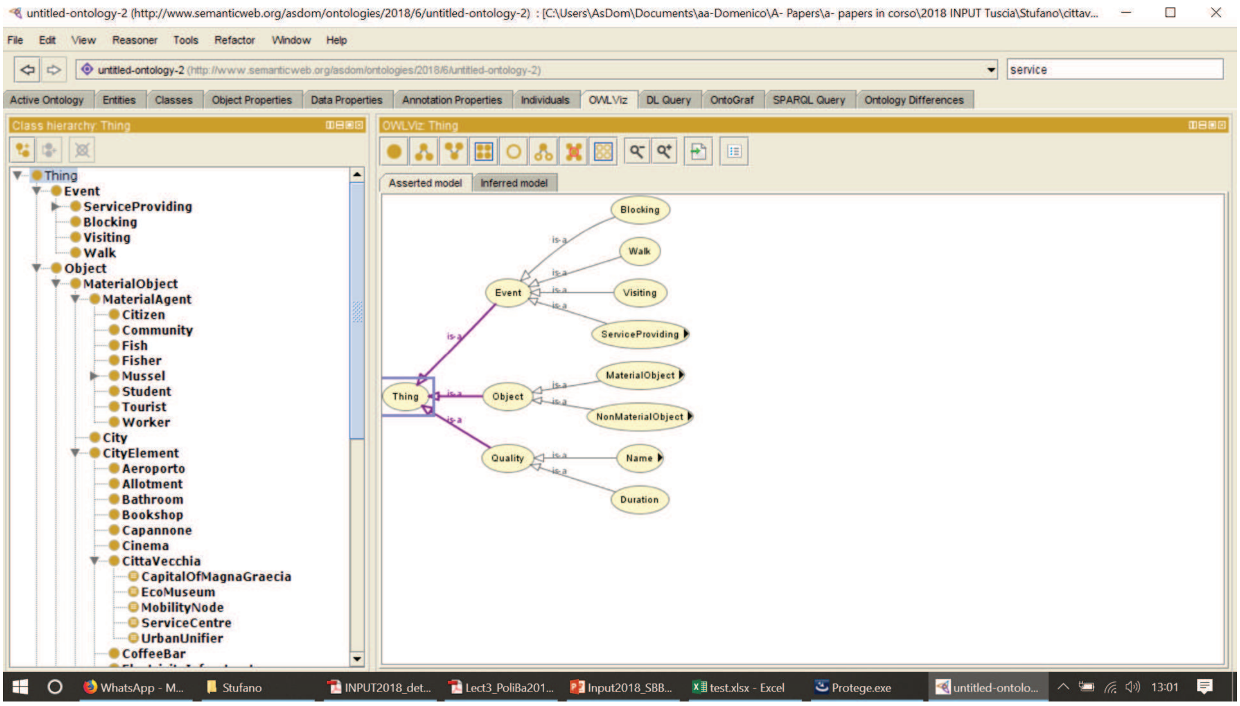

Figure 5: First attempts of ontological representation of the city through Protégé 4.0.

In fact, interactions between agents can improve governance processes, which are highly knowledge-intensive and strongly oriented to the implementing action. In this context, research oriented towards the involvement and deepening of spatial knowledge through group argumentation represents a critical effort towards effective management processes - even beyond contingent and sometimes still unresolved difficulties.

6 CONCLUSION

The concept of smart city proposed by this study has a double-nature approach, aiming at enhancing its complexity-oriented potentials, while pursuing organizational and planning support. It is boosted by the increasing need of structurally and sustainably coping with the inherent complexity of the ecological and sociotechnical system of an urban context. In this vein, a critical issue is the ehancement of the intelligent, multiagent and proactive management of continuous knowledge contributions and contents in urban communities. The objective of this reflection is the research on knowledge models for the creation of 'smart' system architectures for urban planning and management processes.

The paper has reflected about the usefulness of creating an ontology of the city in such a way to derive new conceptual-operational models for city designs and plans, within an extended and refined smart-city framework. In this context, models should look at a polyhedral architecture made for ongoing knowledge support concerning agents’ reasoning and acting in the city. Models should look at city as a complex dynamic system that can be conceptualized by different analysers-reasoners in different and contingent ways according to different viewpoints, so leading to multiple conceptualization. Also, models should concern the abstract organization-structure of a city at its top level of hierarchy which can be maintained at different scales of granularity of the hierarchical structure without losing logical consistency.

Therefore, in a governance-oriented debate, operational features of an applied ontology vision should answer some critical questions: (i) How to deal with the postulated bottom-up navigation to the top level of the ontological hierarchy in which the essential abstract core of the city (the spirit of the city) is located? (ii) How to deal with the different agent or multi-agent knowledge mechanisms which rule the cognitive navigation through the different levels of hierarchy of the organization-structure of a city? (iii) How to deal with time problems, that is about birth, existence, and death of cities and their abstract cores (city spirits)?

This study tried to evoke theoretical and practical analytical modelling questions, exploring perspectives for new robust reasoning frames on the complexity of a city, within a smart-city debate. Next research steps and follow-up will try to address the above quesions, exploring more specifically issues related to the actual building up and management of an operational system architecture, oriented to support urban decisions and ongoing spatial planning processes.

In this context, an intriguing debate on self-organizing cities is increasingly emerging (Portugali 1997), to which knowledge-oriented interaction and connection architectures can add value in a more sensible and sustainable smart-city perspective.

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