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EDITORIAL: SPECIAL ISSUE ON CAAD AND INNOVATION

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1. INTRODUCTION

The concepts and applications of Computer Aided Architectural Design (CAAD) have a predominant presence and impact on architectural design innovation and creativity. ASCAAD, in its 6th international conference, invited the learnt society of academics, researchers and professionals to debate the ubiquitous emerging role of CAAD in underpinning innovative design thinking processes and research in design education. The conference theme covered the following issues:

- Computational research in design pedagogy and in practice
- Intelligent agents, generative and parametric design
- Building Information Modeling and Computer-supported design collaboration
- Ubiquitous computing and interactive environments
- Urban/ City/ regional planning and digital Modeling
- Digital tools in design and construction
- Mass customization

Selected papers have been updated in this publication to reflect the constant quest to balance architectural thinking with operative techniques. It is well acknowledged that the advent of computation and information technology had profoundly altered architectural thinking. Design software and numerical fabrication have recast the role of form giving and shaping environments in architecture and opened up unprecedented opportunities of investigation and links with other scientific domains such as biomimcry, parametric design and modeling of urban and building environments. In this issue authors suggest a continuum between architectural analytical thinking and CAAD systems. Looking at the collaboration between authors of various backgrounds also strengthens this narrative that architecture is expanding beyond its traditional enquiry into historical and theoretical aspects into the world of multi-desciplinarity. It is evident from the diverse publications that CAAD is designed and utilized to expand the architectural pedagogy and practice into initiating and opening up the exploratory grounds of creation and productivity in design.

Sidawi and Hamza (2012) suggest methods of incorporating intelligent and open sourced digital repositories to enhance the incorporation of precedents knowledge. This would help users to gain a critical mass of knowledge that would underpin informed design decisions.

Yu et al (2012) have a situated function-behavior-structure (FBS) model that is capable to reflect the characteristics of parametric design. We propose to apply the results of the protocol analysis in identifying design behavior patterns and those derived from the two levels of parametric design activities.

Timothy (2012) looks at enabling the implementation of parametric modeling and use of digital fabrication in the production and making of architecture. This would help the users to understand the CAD technique or parameters for modeling, translate for CAM production and deal with real world constraints of materials, time and tectonics.

Ibrahim et al (2012) suggest the introduction and implementation of a grammatical thinking approach. This was applied to a cohort of volunteers in the first year who demonstrated the use of shape grammar languages to creating and analyzing narratives of design concepts.

Von Mammen and Taron (2012) implement multi-agent system that models complex biological systems. They argue that this helps users to explore the connection between architecture and natural environment and envisioning biomimetic code as Architecture, Architecture as nature, and nature as codified milieu.

Simone and Antonio (2012) present the construction of a general representation template of user-actor (i.e. agent), easy to implement and flexible enough to structure the large amount of data affecting human behavior and interaction with the built environment. They push the debate on agent based simulation of buildings use to predict and evaluate future building responses to future user intentions.

Finally, the editors would like to thank the chief editor of the ITCON journal for giving them the opportunity to publish these papers in the ITCON journal.

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AN ONTOLOGY-BASED SYSTEM TO SUPPORT AGENT-BASED SIMULATION OF BUILDING USE

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SUMMARY: *The prediction and evaluation of future building response to its intended use and users is a complex task that designers have to face during the design process. As matter of fact, few methods exist that can help designers in such task, despite its importance in the definition of the building quality; norms and regulations, personal designer's experience, post-occupancy evaluation have shown their limit to provide predictive models of the complex phenomenon of human behaviour in built environments . With the increasing of computing power, virtual simulation techniques have been introduced in building design to control, manage and predict complex systems of building performances such as its energy or structural behaviour, but not to representation of buildings while-in-use. The Agent-Based Modelling and Simulation (ABMS) paradigm has been applied in building design to simulation of specific aspects of human behaviour and in specific occurrences (for instance in fire egress simulations), while a more extensive representation of users actions, behaviours, and activities is still missing. In order to overcome this lack, in this paper we propose to support agent-based simulation with a knowledge base, developed by means of ontologies and able to provide a structured system of data about human-building interaction, useful as start hypotheses for Agent-based Simulation. For its development, we rely on the general template of building knowledge management already proposed by the research group (Carrara et al., 2009), extending it to representation of the whole system users-built environment. The proposed general template, configured by the meaning – properties – rules structure, allows the formalization of users/agents entities, whose parameter, attributes and behavioural rules can encode several 'aspects' of real users and their interactions with the other entities (building components, furniture, other people) in a built environment. Currently, a first application has been developed dealing with the virtually testing of a small hospital ward, in order to evaluate the reliability and the potentiality of such approach.*

KEYWORDS: *Building performances prediction; Human behaviour simulation; Agent-based modelling; Ontology-based systems.*

REFERENCE: *Davide Simeone, Antonio Fioravanti (2012) An ontology-based system to support agent-based simulation of building use, Journal of Information Technology in Construction (ITcon), Vol. 17, pg. 258-270, http://www.itcon.org/2012/16*

1. INTRODUCTION

The response of a building to life and activities of future users is a key element of its quality. A building that doesn’t meet the needs of people who should live, work or just spend a part of their life in it can be considered a low-quality design product and, as consequence, the activities performed by people in its spaces could be sometimes hindered by the built environment that surrounds them (Maggi, 2009; Rasmussen, 1964). Despite the importance of determining whether a proposed building will meet the needs of its intended users, the prediction during the design process of future users behaviour in a built environment is still an unsolved problem: one of the main causes is related to the large amount of knowledge needed to do so, its dispersion among different areas and disciplines (cognitive science, ergonomics, environmental psychology just to mention a few) and its lack of integration and formalization in a reliable, usable structure. Further increasing this complexity is the non-deterministic nature of human behaviour itself, which is heavily context-dependent (on such aspects as culture, education, role and dynamics in the society, customs, and beliefs), due to which every human being behaves very differently from others given the same event and same built context.

Norms, regulations and technical literature have implemented knowledge about users and their behaviour in order to support designers during the process of definition of a building solution; nevertheless, despite the presence of significant instances from technical literature and the pervasive feature of normative approaches, their level of generalization and abstraction make the ill-suited to the intrinsic uniqueness and context-dependence of an architectural product and of its interaction with the intended users. As results, sometimes after actual construction buildings don’t work as expected and, quoting Lawson (2006), "the best test of most design is to wait and see how well it works in practice".

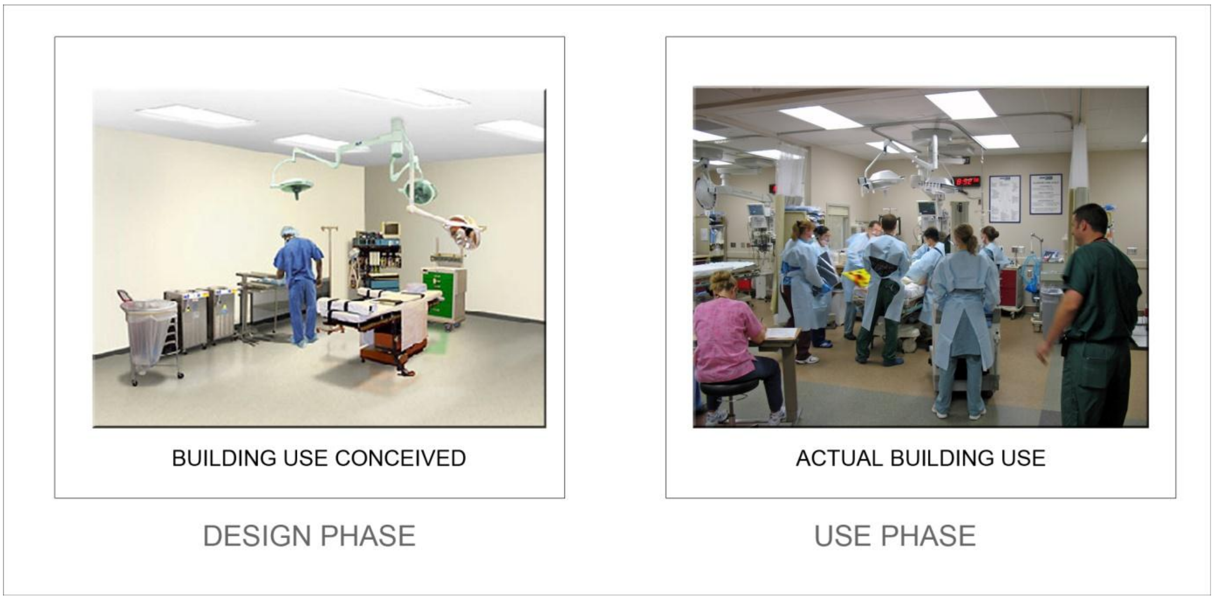

FIG. 1: The building use phenomenon how it is considered during the design phase, and how it actually appears when the building has been realized and occupied.

With the increasing in computing power and the introduction of new simulation paradigms, simulative approaches and tools has been introduced in the design process to support prediction and evaluation of building performances such as its structural behaviour or energy balance. Virtual simulation provides the opportunity to virtually test check the design solution and immediately understand its limits, its unresolved nodes, its critical points; at the same time, when applies to human behaviour representation, some difficulties emerge due to the non-deterministic components of human behaviour and the reliability of the model itself. Among several experiments, Agent-Based Modelling and Simulation paradigm has been successfully applied to representation and simulation of human behaviour in specific occurrences (for instance in fire egress simulation or in prediction of pedestrian movement in public spaces), while, at present, predictive approach dealing with the building general process of use (not only users movement, but also their interactions and activities) is missing.

The research described in this paper aims to overcome this lack, by integrating an Agent-Based System with a knowledge base able to formalize and manage information and data about building-users system, in order to provide a reliable set of hypotheses for the actual simulation. This knowledge base, relies on the general template for technical knowledge representation previously developed by the research group (Carrara et al., 2009), and to its extension from building domain (spaces, technological elements, building components) to the building – users system.

2. AGENT-BASED MODELING AND BUILDING DESIGN

Agent-based modeling and simulation is a new approach to modeling system comprised of autonomous, interacting agents (Macal and North, 2007). An agent-based model is a system modeled as a collection of autonomous decision-making entities called agents, with a view to assessing their effects on the system as a whole. An agent-based model simulate the simultaneous operations and interactions of multiple agents, aiming to represent the system's dynamics and to predict the appearance of complex phenomena (usually named "emergence"), under different sets of initial or boundary conditions. The key notion is that simple behavioral rules at micro level (agents' level), can generate complex behavior. For instance, the macro-level complex behavior of an avalanche is constituted by the micro-level, simple behavior of millions of snow particles, but at the same time itself pulls more snow along with it. This principle was introduced in simulation field by Axelrod (1997) and it is actually known with the acronym of K.I.S.S. (Keep It Simple and Stupid).

In principles, every change of a system, either simple or complex, could be represented by an appropriate set of differential equations. Actually, when the system starts to be rather complex and stochastic components occupy a main part in its behavioral structure, the complexity of this set of equation increases exponentially, becoming unmanageable and not fully reliable. Agent-based modeling shows its full potential to represent systems difficult to manage with classical mathematical methods , in particular when (Bonabeau 2002):

1. Individual behavior is not linear and can be characterized by decision–making, if-then rules, nonlinear coupling. Describing discontinuity in individual behavior is difficult with differential equations;
2. Individual behavior exhibits memory, path dependence, decision-making process, event and context dependence;
3. The system is not linear.

Although the idea of Agent-based modelling was developed as a relatively simple concept in the late 1940 but, because it requires computationally intensive procedures, it did not become widespread until the 1990s.

With the increasing of computational power, first application has been developed to predict and evaluate specific aspects of users' behaviour in not-yet-built buildings.

As previously explained, Agent-Based Modeling is worthily applicable to systems consisting of a sum of independent entities, behaving autonomously in the environment; if we try to look at the process of use of a built environment by an agent-based modeling point of view, what we see is a series of agents, representing users, acting autonomously and interacting with the environments and with other users/agents. The intuitive principles of Agent- Based Systems, the matching with "building use systems" and the power of ABM approach has led some researches in the attempt of applying it to prediction of building's use and functioning.

The early studies in fields related to building design were the development of model-driven simulation of people movement in large buildings such as airports (Krijnen et al., 2009), internal commercial areas (Cenani et Cagdas, 2008) or to representation of human behavior in public spaces (Yan and Kalay, 2005) in order to evaluate the use of paths in designed spaces or how designed spaces affect the users' status. At present, in such models everything is reduced to representation of specific occurrences and/or specific aspects of behavior (i.e. fire egress simulation), while a more integrated and comprehensive representation of user behavior in built environments, enough developed to help different designers to understand the consequences of their design choices on future users, is currently missing. This representation should be composed of :

1. *Representation of knowledge related to user and building interaction:* a formalization of knowledge from various disciplines such as cognitive science, ergonomics, environmental psychology can represent the different modalities of interaction among user and other entities.
2. *Representation of dynamics of human behavior and of the modalities with which it is affected by the built environment*: human behavior is context-depended and is characterized by an highly dynamic nature; the most valid representation is the phenomenological observation of it starting from the knowledge of structured relations system.

Due to number and difference in typology and objectives of researches in agent-based modeling, there is not a universal definition of ‘Agent’. Roughly speaking, an entity can be considered an agent if it has some degree of autonomy, and if it is able to understand the environment surrounding it, develop a process of decision making, and adapt its behavior/actions depending on the status of the context (Casti, 1997; Bonabeau, 2001). Anyway, in any agent’s definition, the fundamental feature is the capability to make independent decisions; as results, agents are not passive entities, but active components of the model.

The agent’s set of characteristics has been described in good details by Macal and North (2007), accepted by the research community and can be summarized in these core points:

- *Identifiability:* an agent is a discrete, well-delimited individual who has his own set of properties and rules of behavior;
- *Autonomy and self-control:* an agent acts in any case independently from other agents (which however can interact with) this means that several agents will adapt to the same context in different ways;
- *Location in an environment through which it interacts with other agents*: the agent is situated in an environment which sends him information and affects/ is affected by agent’s behavior.
- *Goal-oriented*: each agent tends to reach the objectives by adapting his behavior; changing the objectives is the first way to create and observe significant variations in the emerging behavioral phenomena.
- *Learning ability and flexibility:* an agent is able to catch information from the environment in which it is located, to store and manipulate them in order to adapt and change its behaviour.

3. THE ONTOLOGY-BASED TEMPLATE OF USER-AGENT

In relation with the characteristics set out above, the aim of our research is to define an ontology-based template to formalize the knowledge about the user-agent and its interaction with other entities, in order to support the agent-based simulation. Individual agents can be considered as the central element of agent-based modeling and therefore, acting on its features (attributes or behavioral schemes), it is possible to generate significant changes in the output phenomenon provided by the simulation. Therefore an appropriate template of agent, implementable by means of ontologies, must have in its representation a few key elements:

- *Identification***:** An agent must be univocally identifiable within the system, and it is essential to distinct it from the other entities that compose the built environment and from other agents. At the same time, the identification system allows us to reconstruct the system of higher-level classes of the agent, tracing back to the basic taxonomic structure. The construction of the taxonomic tree is essential for the inheritance of agent characteristics, such as attributes, values associated with them, systems of rules.
- *Attributes*: The structured set of attributes contains all the features necessary for the representation of user-agent and a set of associated values (e.g. numbers, strings, algorithms, procedures, etc.) to each attribute. The definition of the value of these attributes (partly inherited from the system of higher-level classes), defines the characteristics of user according to the objectives of the performance-simulation.

- *Status*: "state or condition with respect to circumstances" (*Merriam-Webster.com*. 2011. http://www.merriam-webster.com). Merriam-Webster); in our system it corresponds to a fixed set of values and associated with some specific attributes, in order to represent a particular state of user-agent in specific time and in direct dependence with the context.

- *Goals*; each user placed in the model has to perform some activities which affect its behavior. Each activity is described in terms of objectives and the agent aims to achieve them through his behavior. The goals are dynamic and change according to scheduling, time and events in the process of simulation. They are also divided into several levels depending on the activities breakdown in a series of simple actions.

- *Interaction domains and proxemics*: the user, when populates the model and carries out simple or complex activities, interacts with other context entities or other users-agents. Such interactions occur when these entities are to be at points close to Agent: the *locus* composed by set of points in space where these interactions are established is called domain of interaction. To different kind of interaction correspond different domains, with specific shapes and dimensions.

- *Set of behavioral rules*: human behavior in a building is essentially complex and non-deterministic, but it can be represented by a simulation based on a combination of relatively simple algorithms. These rules, hierarchically structured on multiple levels and linked together, can go through to represent a sequence of simple actions of even very complex tasks. The use of techniques of artificial intelligence also allows to set up a simple scheme of rules (if-then etc.) and to generate, during the simulation, a quite independent behavior of agent.

One of the main factor in users' behaviour prediction is the complexity of human behaviour in itself and of human interaction with buildings: while a human being is within an environment, he processes a wide spectrum of information , taking a large number of decisions and performing conscious and unconscious actions relating not only to the purpose of behaviour but also to different contexts at the same time (Koutamanis et al., 1996). In accordance with this complexity, the relationship between built environment and its human inhabitants has been studied in several fields such as psychology, sociology, ergonomics, philosophy, proxemics and cognitive science among others. Their central aim is to describe how people respond to and behave in built environments, both under normal and under stressful conditions. A part of this large amount of data provided by these different research fields could be useful hypotheses for an agent-based simulation, able to predict future building users behavior but, nevertheless, the lack of integration among these "bunches" of knowledge makes almost impossible to use them in actual design. This large amount of knowledge could be implemented within these features, which essentially correspond to a breakdown of knowledge concerning the human being and his behavior within the built environment, and its relationship/interaction with all those entities that surround him (spaces, building components, equipment, furniture, other agents). This element can be considered as a knowledge base, able to represent a structured set of entities involved in the representation of:

1. The building design solution, in terms of spaces, building components, furniture, equipment etc.;
2. The process of use in terms of agent-users considered, their actions, their behaviour.

Such knowledge base should be able to, at the same time, highly flexible and implementable in order to admit and support:

1. The management of information and data and their modifications in order to check possible variations of the system;
2. The implementation of information from different disciplines in order to build an updated and reliable system.

The features and modalities of construction of a building knowledge base has been the central part of several researches related to CAAD area. Among different solutions proposed in the recent years, we choose to represent, manage and organized such knowledge base by means of ontologies. In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge. An ontology is a representation vocabulary, a conceptualization structure and, given a domain, its ontology forms the heart of any system of knowledge representation for that domain.

The representational primitives are typically classes (or sets), attributes (or properties), and relationships (or relations among class members) (Gruber, 2009). We can consider an ontology system as an "intentional semantic structure which encodes the implicit rule constraining the structure of a piece of reality"; the aim of ontologies is to define which primitives, provided with their associated semantics, are necessary for knowledge representation in a given context (Guarino, 1995; Bachimont 2000).

Ontologies use to representation and formalization of knowledge base consists in two main features:

1. Homogeneity of representation of heterogeneous classes;
2. Accessibility from external systems (humans or computers).

The first feature is relevant for the purpose of our knowledge base; as we decide to implement in the Knowledge base not only information related to building, but also to the process of use, and because the entities involved in these two domains are not separated but strictly connected, an homogeneous way of representation is necessary in order to represent such connection. The ontology-based representation offers a common way to represent different kinds of entities (actors, spaces, activities, building components, furniture, equipment) in order to build a homogeneous knowledge base in which all the entities can be represented with their attributes and their relationships.

Ontologies have been developed to provide a computable knowledge base to support machines reasoning. In AI, knowledge in computer systems is thought of as something that is explicitly represented and operated on by inference processes and knowledge bases are thought of as something explicitly represented and rigorously structured in order to let computer systems refer to and operate with them. The role of ontologies is so important that some researchers state that "Any useful software cannot be written without a commitment to a model of the relevant world to entities, properties, and relations in that world" (Chandrasekaran et al., 1999). They provide a Domain factual knowledge, representing knowledge about the objective realities in the domain of interest (objects, relations, events, states, causal relations, and so forth). In our case to be machine-accessible allows the agent-based simulation engine to get (or with the use of a "bridge" software) data automatically and information about the building model and the use process to be simulated, and to use them as set of initial hypotheses.

When we analyzed the ontology-based approach in representing knowledge about human behaviour in built environments, users' profiles, actions and activities. the advantages of this approach offers the possibility to formalize in a single base, and in a single representation, knowledge provided by different knowledge domains . This is particularly relevant for our purposes because, as described in the first part of this paper, knowledge related to human spatial behaviour is not yet organized in a single system, but it is spread in several domains, each with its own set of approaches and methodologies. The formalization by means of ontologies allows, on the contrary, to implement such knowledge using as central elements always the same entities, recognized in advance because of their involvement in the definition of the building design solution, of its use and of its users. At the same time, an ontology system allows to share knowledge among different researchers/designers, and to continuously implement the knowledge base, offering a reliable, specific and up-to-date knowledge about domain considered. In our proposed approach, the knowledge based developed by means of ontologies can be considered as a "bridge" between the behavioral phenomenon in real world and its simulation in virtual world (fig.2).

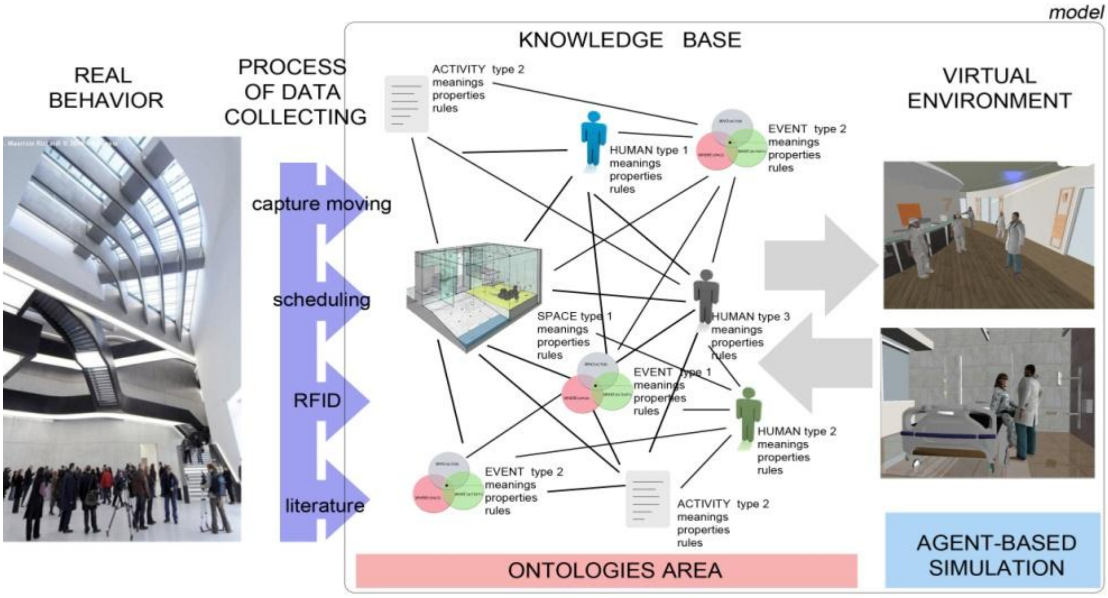

FIG. 2 Ontologies as bridge between real world phenomenon and simulation

Several methods have been developed to collect data and knowledge about human behavior in built environment, by observing and measuring the real phenomenon and subsequently proceed with an abstraction process to obtain general concept to reuse in new simulations. Some collecting approaches have used video-tracking systems (Yan and Kalay, 2004) or RFID tracking (Tabak et al, 2008) to obtain data about movement and position of users in the built environment. Other research have been focused more on obtaining data about activities performing, by means of direct observation and concurrent scheduling of users' actions. Even general literatures, such as manuals for designers, provides a knowledge usually obtained by deriving general rules from the observation of a specific case phenomenon or of a series of cases.

4. THE MEANINGS-PROPERTIES-RULES STRUCTURE AND ITS APPLICATION TO AGENT STRUCTURE

To develop this knowledge base by means of ontologies, we choose to rely on the general structure for knowledge representation already presented and discussed among the scientific community by this research group (Carrara et al., 2009), and to extend its application field from the building domain to the building-human interaction domain. In such template, each entity involved in the building design process (spaces, building components, furniture, etc.) is represented through ontologies in terms of its unambiguous definition-identification, of its properties (including behavioral properties) and of its relations with the other entities to which it is connected.

This general template, although developed to represent entities related to the definition of the building, can be extended because of its generality to the representation of actors/agents as "living entities" but part of the building organism.

Its related representative structure is based on the definition of three main entity feature in which knowledge can be formalized: Meanings, Properties and Rules.

Meanings: includes all declarative aspects related to entity/agent considered; a first, relevant information needed is the definition of which class is the agent derived from. It helps in making explicit agent's aspects as role, capabilities, tasks, goals. In this feature it is possible to represent the necessary information related to the first of the agent structure, the identification aspect, as derived from the agent-based paradigm. Depending on the related class of the agent, and of its role in the use of the building, an identification code is assigned during its process of instantiation. It allows the system to distinguish it (and its features) from all the other entities surrounding it, both part of the building or other agents. At the same time, the specification of the deriving class “locates” the agent in the knowledge structure, defining implicitly which properties and which kind of interaction it will have with other entities. The description of goals is extremely relevant for an agent-based system; as matter of fact, it is the objective of agent’s behavior adaptation, and its correct formalization can help it in providing a behavior more similar to reality.

Properties: This domain includes all the descriptive-relational aspects and their values (in a broad sense) members. These properties, by means of which it can be entered and displayed the attributes associated to user-agent structure, could be extrapolated and used in procedures such as calculation methods, algorithms, computational systems and Agent-Based System (ABS).

Each property has an associated memory-slot in which information is stored to represent specific aspects of agent’s features. For instance, if we are using two agents to represent the behaviour of two pedestrians, a young and an elderly person, they’re same property SPEED_MOVEMENT will have two different values, higher in the case of young person, lower in the case of the elderly person.

The attribute values can be determinate a priori or computed during the simulation; it can be fixed or vary during time (for instance the values associated to agent’s position attributes). Properties can represent different attributes of entities/agents such as geometrical, topological, behavioural, social, task and role dependent ones.

A structured system of properties with an associated system of values is what we defined as *Status*, accordingly with the same definition already accepted in Agent-Based System researches. The properties related to the status can be highly affected by context and other agents status and behaviours.

Rules: they represent relationships, connections and interactions among different entities and in particular among agents and other entities (both building elements or agents). Such system of rules is able to provide:

- A relational network making explicit all different relationships among entities and agents;
- A set of algorithms to be computed to simulate the variation of status of the system building-agents;
- A set of possible agents behaviors in terms of actions, entities involved and modalities of running/computation during simulation time.

This system of rules consists of a series of different relationships, arranged in a semi-lattice structure, whose rules are the connective” synapses”. Inside the user's structure it is possible to find three broad groups of rules: relational rules, reasoning rules, behavioral rules.

The *relational rules* are necessary to collocate the entity (in our case the user) into the structure of the knowledge base: these rules specify the hierarchical relationships between the entities, the relations of aggregation and assembly, the relationships of transition between prototype and instance, and inheritance relationships. It also allows also other kind of relationship among agents and spaces, building components (for instance which room or workplace is associated to a specific user/agent, or which doors it is allowed to passing through.

The *reasoning rules* are essentially algorithms, equations, code language for formal analysis and computing that bind only to certain aspects of internal entity or multiple entities. They are selective, since they can check and change specific values and parameters associated with each entity in relation to the status of the system and context. Analysis, checking, evaluation and control of concepts associated to specific entities is performed by means of inferential engines, with deductive ‘If-Then’ type procedures. For instance the system, computing and comparing agent position data and coordinates of a room, can deduct if the agent is inside or outside the room, information necessary during the running of the simulation of building while-in-use.

The *behavioral rules* are all the rules necessary to formalize user/agent's actions, activities and behavior. They are algorithms that allows agents to show intelligent behavior, and to adapt it to different status of the context depending on specific and also variable goals. For instance, they have to formalize which actions and decisions an agent has to perform in order to reach a specific space of the building. There rules are the hypotheses that will work as base to the actual agent-based simulation. They are agent's class-dependent (because different kinds of agents can behave differently), and objective-dependent (because agents behaviors are different when oriented to different objectives). At the same time, such system of rules also represent how an agent can use or interact with specific elements of the built environment; for instance it can formalize the systems of agent's action necessary to open a door, use a machinery, or moving through corridors.

Another part of the system of behavioral rules is necessary to control and simulate interactions among different agents, such as mutual collision avoidance during movement, or agents' actions coordination during a cooperative activity. These rules take into account a large amount of knowledge non only related to activity merely performing, but also to the social, cultural, role-dependent factors that can affect such occurrences.

Sometimes, this first level of rules is overlapped by a second layer that manages, monitors and invokes the rules of the performance level. This second layer is needed to achieve a better adaptation of human behavior in the events and context. This allows the agent to receive information from the context, edit and create a structured set of actions that form the behavior. Using the first level of internal rules, the performance level, it is also possible to represent the domains of interaction as part of the agent that allows the activation of' interaction with other entities. They are represented as trigger areas around the agent, which is undergone to a process of continuous check to detect the entry into the area of interaction pertaining to the agent. These domains of interaction vary as a function of interactive aspect considered and depending on the location of agent in the model. Another element necessary to reliable simulate agents behaviour is the system of *domains of interaction*.

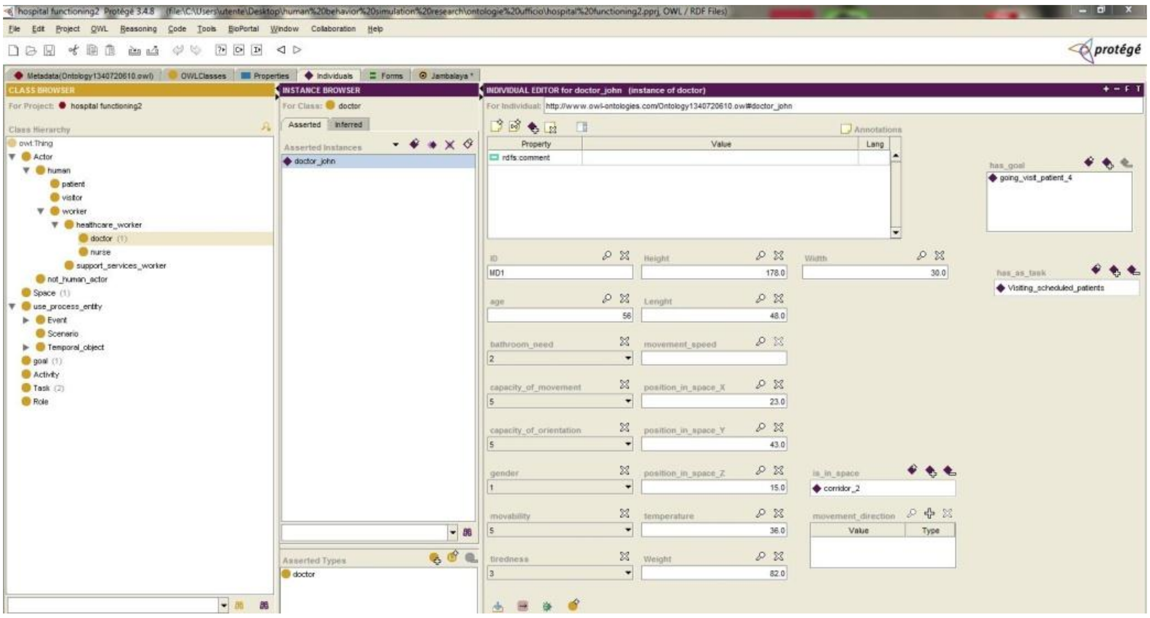

FIG. 3 A part of the agent template developed in protégé (used for the development of first implementation of the proposed approach).

5. A FIRST IMPLEMENTATION: USERS' BEHAVIOUR IN A HOSPITAL WARD SIMULATION

In order to test and clarify our approach and the use of ontologies to support agent-based simulation (for building performances evaluation purposes), we have developed a first implementation concerning users' behavior simulation in a hospital ward. As support of such simulation, we prefer to use not a "pure" agent-based software (such as Netlogo or Swarm) but to rely on a more versatile game engine (Virtools 4.0) with integrated AI libraries. The advantages of this choice are basically two: on one side, it allows to import building and environment model from common software such as 3D Max Autocad or Revit, and this feature is useful in order to work on building models actually results of a design process, and in which a lot of data and semantics are available. On the other side, the scripting level in Virtools allows a better controlling of agent behavioral patterns, and the possibility to load data from external systems (for instance excel files, XML, etc.). To develop the knowledge base and the semantics necessary as hypotheses of our simulation, we have chosen to use the ontology modelling system *Protégé* (version 3.4.8), a Java-based open source ontology editor and knowledge-base framework.

In hospital buildings, operational efficiency and, more generally, the building functioning is heavily influenced by the design of the built environment; users' behaviour (doctors, patients, visitors, nurses, etc.) is a good parameter to verify the functioning quality of the designed built environment, and its good simulation allows to define the location of some “problem areas” (Cohen, 2010). At the same time, although hospitals are relatively complex buildings, as currently conceived and designed they are highly specialized “machines” whose purpose is to “fix” ailing patients. They use a relatively straight-forward, standardized use pattern, which is advantageous for this research since it provides a comprehensive, and agreed-upon, data set against which the model can be tested.

A first knowledge base related to building entities (spaces, components, furniture, etc.) and to agents involved in the process of building use has been developed by means of ontologies; some agents profile (doctor, nurse, patient, visitor) have been developed, while the process of use considered is a system of activities related to the usual functioning of the hospital (doctor and nurses working in their workplaces, checking patients' status, visitors coming to meet some patients, etc.). This knowledge base is integrated with the Virtools simulation engine, in which the built environment and the agents are geometrically represented in a virtual environment, and where the single agents behaviour and actions are computed by means of pre-scripted algorithms and specific Artificial Intelligence libraries. The result is a simulation of the building use phenomenon more reliable and similar to reality. The agents show more complex behaviours and, at the same time, more coordinated interactions with other agents and with entities composing the built environment. The result is a simulation environment “semantically rich”, where the building use phenomenon is still generated by the sum of single agents' behaviours, but they are more coordinated and reliable, and their degree of arbitrariness is highly reduced.

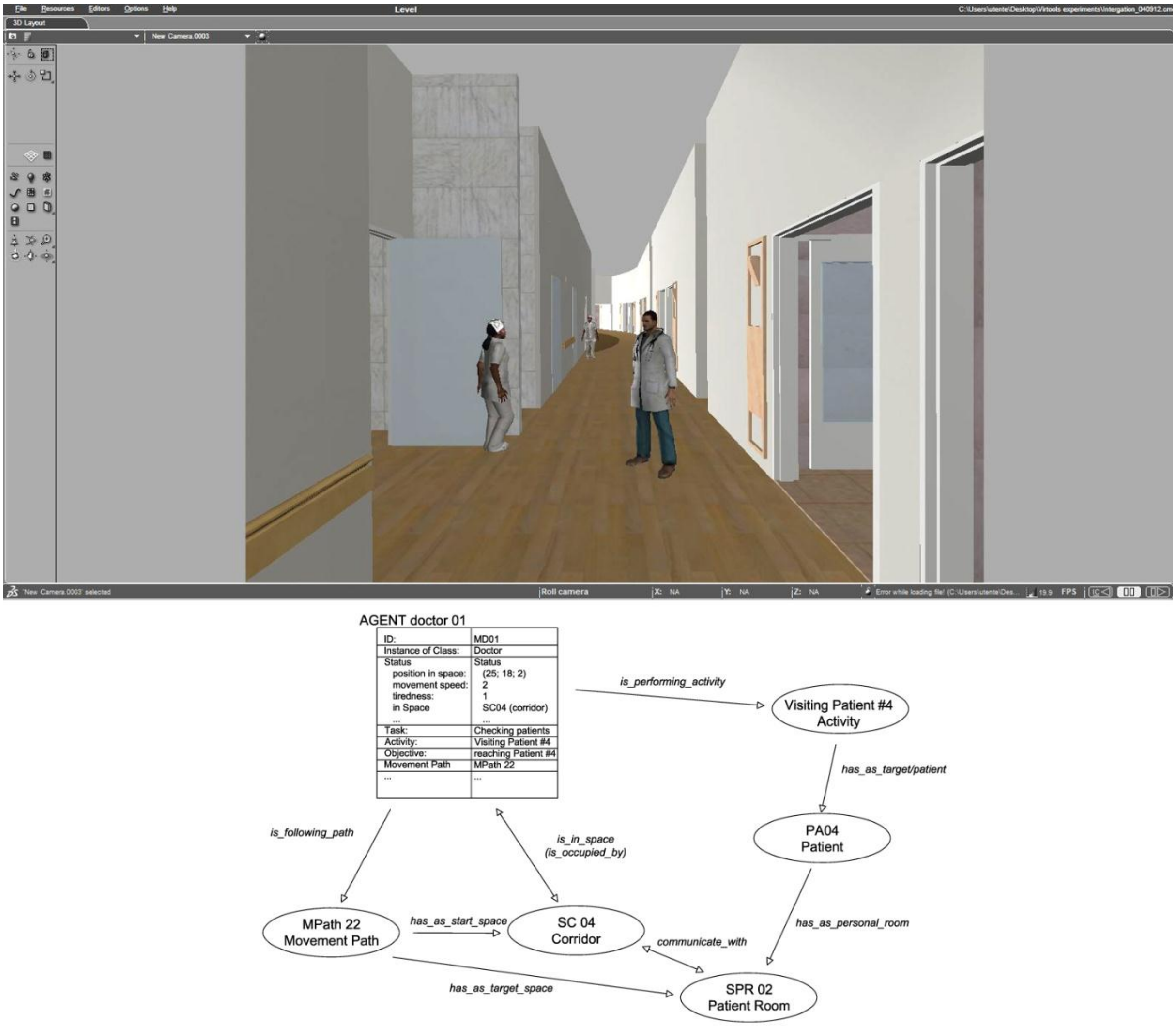

FIG. 4 The Virtools simulation environment and some relationships among entities represented by means of ontology and used as hypotheses for the agent's reasoning.

6. CONCLUSIONS

Prediction and evaluation of future building response to users' behavior and activities is a complex task that architects have to face to improve the quality of the design solution. With the increasing of computing power, simulative approaches – in particular Agent-Based Systems – have been introduced in the design process to provide a qualitative representation of how the built environment will interact with future use process and future users. Although extremely powerful in theory, agent-based systems applications to building use prediction have been quite limited to representation of specific aspects of human behavior and/or in specific building status (for instance pedestrian movement in airports or egress during fire), while a more extensive representation of behaviors and activities of users is still missing.

To overcome this gap, in this paper we proposed an approach to support agent-based simulation of building use; at its core there is the choice to integrate an Agent-Based System with a large knowledge base developed by means of ontologies. Such knowledge base represents in a single semantic network, on one side all the entities involved in the definition of the building solution (spaces, technological components, furniture, equipments) and on the other side future users profile (workers, visitors, etc.) and the system of their activities.

To develop this knowledge base we rely on the general knowledge management template proposed in the past by our research group, and on its extension from the representation just of the building entities to the representation of the whole building-users system. As result, a more “semantically rich” system of hypotheses will provide a more reliable simulation of human behavior, not limited anymore to specific aspects, but able to manage and simulate all the complexity of human-building interaction. An Agent-Based System supported by ontologies will reduce its degree of arbitrariness related to single agents autonomous decision-action processes, and provide a more coherent representation of building-in-use.

The general aim of this research is to provide a reliable approach to simulate human behaviour in t design stage;. We believe that a better prediction of how people will use and interact with the built environment will necessarily impact the design process. Designers could be allowed to virtually test the future building without stepping into the actual construction. The possibility to “anticipate” the building functionality evaluation allows designers to intervene in time and solve possible emergent usability problems, critical points, or inconsistencies; The results will be the, improvement of the quality and liveability of the final product and, at the same time, the reduction of wasted time and of unnecessary costs related to post-construction interventions.

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