AN ONTOLOGY-BASED TEMPLATE OF USER-ACTOR TO SUPPORT AGENT-BASED SIMULATION IN BUILT ENVIRONMENTS

DAVIDE SIMEONE[1], ANTONIO FIORAVANTI[2]
Sapienza University of Rome, via Eudossiana 18, 00184, Rome, Italy
[1]*Email: davide.simeone@uniroma1.it*
[2]*Email: antonio.fioravanti@uniroma1.it*

Abstract. The behavior of a human being in a building, its activities, its interactions with it and with other people are certainly a highly complex phenomenon extremely hard to predict and evaluate. At the same time, the response of a built environment to future users' needs is one of the key factors of its performance. The Agent-based Modeling paradigm is considered potentially the best way to represent human behavior but, in the building design field, its experiences are limited to representation of partial aspects of human behavior in discrete events. Currently, a more "extended" representation of human behavior able to offer an overview of the human activities related to the building 'functioning', is missing,. This lack is due to the complexity of interaction among users and built environment, and to the extensive knowledge, provided by different disciplines, needed to reliably represent it. The proposed research focuses on the construction of a general representation template of user-actor, easy to implement and flexible enough to structure the large amount of data affecting human behavior. The development of the ontology-based template shown in this paper can lead to a user-agent's entity whose parameters and behavioral rules can encode and represent several 'aspects' of real users and their interactions with the other entities (building components, furniture, other people) in a built environment.

1. Introduction

The response of a built environment to the activities and actions performed by the future users is one of the key factors in the evaluation of its performances and 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 results, the activities performed by people in its spaces could be sometimes hindered by the environment that surrounds them.

Despite the centrality of future users in a building design process, the prediction of human behavior in a built environment is still an unsolved problem: one of the main causes is related to the large amount of knowledge domains involved in it (cognitive science, ergonomics, environmental psychology just to mention some of them) and, at the same time, to the difficulties related to their integration and formalization in a reliable, usable structure. To increase this complexity come also into play the assumption that human behavior is totally nondeterministic and, in addition, every man behaves very differently in relation to the same event and built context.

The building usage evaluation and the performance forecasting in response to users' needs is one of the most difficult resolution points in the design process; at the moment, the related knowledge needed during the design phases is mainly collected in two areas: the technical literature and the practical knowledge of designers. The first one, despite the presence of significant instances like Neufert and Adler works, has shown its limits in behalf of a more pervasive approach influenced by a higher number of elements and structured in complex ways. The second one, related to practical experience of designer, is generally limited to specific cases analyzed in the past and difficult to be applied to buildings whose characteristics are not similar (at various scale of the project) to previously studied cases.

Quoting Lawson, "the best test of most design is to wait and see how well it works in practice": the simulation provides exactly the opportunity to check the design solutions proposed and immediately understand the limits, the unresolved nodes, the critical points; at the same time, there are some representation difficulties related to the reliability of the model itself. The non-deterministic components of human behavior, the direct dependence from the context and the uniqueness of the design product are still obstacles those can affect the results of the simulation. In the first part of this paper are analyzed the central concepts and some of the current limitations of Agent-based simulation applied to building design; in the second part it is shown how the ontology-based template of knowledge representation model, previously developed by the research group (Carrara et Al, 2009), can be adapted and integrated with the agent-based approach in order to obtain a more reliable representation and simulation of human behavior in building. The proposed connection between agents and a knowledge base built using ontologies can affect meaningfully the use of ABMS as new way to verify and evaluate the quality of a design product.

Figure 1. The importance of human behavior component in prediction of building design solutions

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). The Agent-based Modeling shows all its potential to represent systems hard to represented with classical mathematical methods. It is really useful 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.

ABM is most natural for describing and simulating a system composed of “behavioral” entities. In principle everything can be done with equations but complexity of differential equations increases exponentially as the complexity of behavior increases. Instead, using the ABM is possible to maintain a very low level of complexity of the rules system that govern the behavior and, at the same time, get to represent very complex phenomena (such as users’ behaviors in a building).

The early studies in fields related to building design were the development of model-driven simulation of people movement in large built spaces such as airports (Krijnen 2009) or internal commercial areas (Cenani et Cagdas 2008) in order to evaluate the use of paths in designed spaces or how designed spaces affect the users’ status. At present in the current models everything is reduced to specific occurrences and/or specific aspects of behavior (i.e. fire egress), using not integrated computational models of way finding and physical perception.

However, an extensive and exhaustive representation of the user behavior and human-building interaction, 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.

Roughly speaking, an entity is an "agent" if it has some degree of autonomy (using a perception-action cycle) and if it is distinguishable from its environment by some kind of spatial, temporal, or functional attribute. As asserted in the theory of' agent-based modeling, the main characteristics of agent can be found in the following points (Macal and North, 2007):

- *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) this mean 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 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 behavior.

3. Ontology-based Template of 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 to support an agent-based simulation. Individual agents can be considered as the central element of agent-based modeling and therefore, acting on its features, it should be possible to generate significant changes in it throughout the simulated system. Therefore an appropriate template of agent must have in its representation a few key elements:

- *Identification***:** An agent must be uniquely identifiable within the system, it is essential to distinct an agent from the entities that compose the built environment and from other agents. An identification system allows us to reconstruct the system of higher-level classes of its 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 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); 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 straight 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 proximics***:** the user, when populates the model and carries out simple or complex activities, interacts with other context entities or other user-agents. Such interactions occur when these entities are to be at points close to Agent: the locus composed by set of points in space from which these interactions are established is called domain of interaction.
- *Set of behavioral rules*: human behavior in a building is essentially complex and non-deterministic, but it can be represented by 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 observe a quite independent behavior of agent.

A series of data may be added within these features, which essentially correspond to a breakdown of knowledge concerning the human being and his behavior, and its relationship with all those entities with which it interacts (components, equipment, furniture, other agents).So, there is need of a template able to represent the relational system and, at the same time, highly flexible and implementable in order to admit and support:

1. The management of information and data and modifications in order to check possible variations of the system;
2. The implementation of information from different disciplines in order to have a system up to date and thus more reliable.

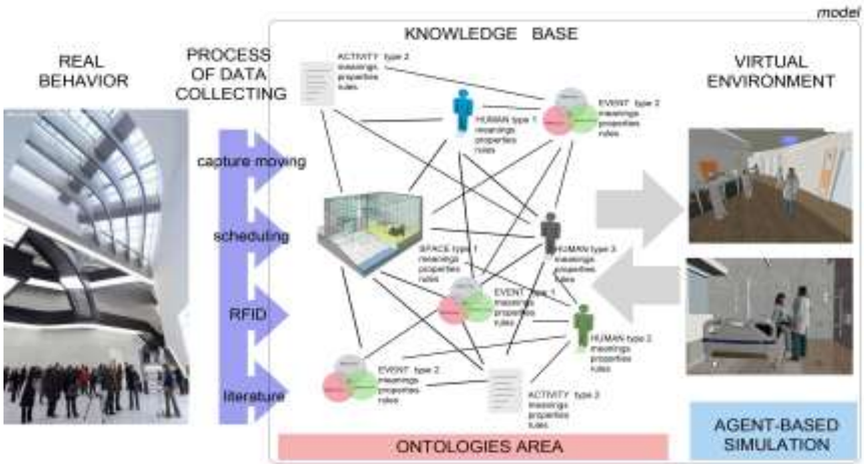

Figure 2 Ontologies as bridge between real world phenomenon and simulation

Whereas a user is just one of the entities involved in the design process, the template proposed by the research group, based on use of ontologies, can be applied for the purposes of knowledge representation and its related systems of relations with other entities.

Each entity will involved in the design process 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. The general template of knowledge representation proposed by the research group (Carrara et al. 2009) defines three representative aspects which can be applied to knowledge management related to building users: Meanings, Properties and Rules.

Meanings: includes all declarative aspects related to entity considered, in this domain can be bound and edited a number of user-agent's definitions those are context-dependent and not exhaustive. Comparing the meanings structure with the agent’s one derived from agent-based modeling, it is possible to represent completely inside of this domain the information regarding the identification of the user-agent.

Through all the meanings, a kind of entity identification code can be associated and with that it is possible to distinguish it from other entities and the context. It can also be represented (in part using the system of rules described below), the set of higher-level classes where inheritance of the properties that characterize it.

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 ABS.

Inside the set of properties it is possible to provide memory-slots in which store information to represent the status (which will vary according to certain values associated with some properties) and goals, whose variations affect the status and behavior of the user.

Status and goals have a high degree of context and event dependence and therefore they are essential to give the agent the capacity to adapt to the built environment and events.

Rules: represent the connections between the entity-user and other entities with which it relates. The system consists of a series of many to many relationships, arranged in a semi-lattice structure, whose rules are the connective synapses taking up the metaphor of the human brain. 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 basically to place the entity (in our case the user) into the structure of knowledge, these rules shall specify the hierarchical relationships between the entities, the relations of aggregation, the relationships of transition between prototype and instance , the inheritance relationships.

The *reasoning rules* are essentially algorithms, equations, code language for formal analysis and calculation that bind only to certain aspects of internal entity or multiple entities. They can check and change values and parameters associated with each entity in relation to the status of the system and context.

The *behavioral rules* are articulated into two levels: the first contains all the rules that might be called performative and contain simple if-then rules or more complex algorithms, depending also on grade of resolution of the simulation. In this subset, rules are related to dynamic interactions with other entities of the building and with other agents. These rules are integrated with the reasoning rules to simulate the process of interaction between entities and to represent phenomena such as movement, according to attributes from status and goals. This first level of rules is overlapped by a second layer that manages, monitors and invokes the rules of the performance level. This double layer is needed to achieve adaptation of human behavior in the events and context. This allows the user to receive information from the context, edit and create a 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.

4. Conclusions

In this paper we have proposed the developing of an ontology-based template of agent useful to make more reliable an agent-based simulation of human behaviour in built environments. We believe that the use of ontologies can provide a needed bridge between the large amount of data about behaviour that we already have in several fields and the world and tools of ABM. Currently the research group is developing a first implementation to verify the reliability of the model and its impact in the design process. The tools used for these first experiments are an ontology editor (Protégé 3.4.7) and a game engine (Virtools 4.0) integrated by means of AI libraries to represent agents' decisions, actions and their consequences on other entities in the simulation environment.

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