An Event-Based Model to Simulate Human Behaviour in Built Environments

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Abstract. During a design process, few methods allow designers to evaluate if and how the future building will match and affect its intended use and its intended users. Computer simulation techniques have focused on prediction of human behavior in built environments in order to overcome this lack; nevertheless, their applications are limited to representation of specific behavioral aspects while a reliable representation of building response to actual use is still missing. Based on current developments in the video game industry, the research described here aims to establish a new approach to simulating human behavior in buildings, centered on a clear definition of use scenarios as specific structures of active entities called Events. They provide information about occurrences happening during the use process in terms of Actors involved, Activities performed and Space where the event takes place. Equipped with AI engines, events control and coordinate the actors’ behavior during the simulation, representing their interaction, cooperation and collaboration.

Keywords. Building use simulation; event-based model; human-built environment interaction.

RATIONALE

In his 1959 seminal book, S. E. Rasmussen symbolically compared the architect’s role to a gardener, waiting for his/her design to become alive - “flourish” - in order to see if it will be a success or a failure. What Rasmussen (and others) had in mind was the importance for designers of fully comprehending how a future building will respond to its users and their activities. Still, few methods exist that can help designers to really understand how their design choices and decisions will affect future users life and activities. Norms and regulations, past experiences and analysis of already built environments can support designers by providing some idea of how the future building will be experienced but, because buildings are unique products, this picture is necessarily vague and uncertain (Maggi, 2009; Amendola, 2009).

The difficulty of predicting future users’ behavior is a huge obstacle to reaching a successful design result: unlike other design products, buildings cannot be fully understood without knowing how and by whom they will be used. Many well-known buildings, such as the Pruitt-Igoe plan by Yamasaki or the Unité d’Habitation by Le Corbusier, considered Architecture’s masterpieces, have failed terribly in trying to meet the needs of their real users.

Human spatial behavior in built environments is a highly complex phenomenon, difficult to predict and to generalize. When a human being is placed within an environment, s/he processes a wide spec-
trum of information, makes a large number of decisions and performs conscious and unconscious actions relating not only to the purpose of his/her behavior but also context at the same time. As direct consequence of such complexity, a large amount of knowledge about human-built environment interaction is needed in order to provide a reliable representation of such phenomenon. Several disciplines of study, including cognitive science, ergonomics, environmental psychology, and social sciences, have focused on specific aspects of this interaction, and much potentially useful data is already available. Yet the lack of integration and formalization of such knowledge in reliable, computationally accessible structures, make it almost unavailable to architectural designers.

Further increasing this complexity is the non-deterministic nature of human behavior itself, which is heavily context-dependent (on such aspects as culture, education, role in society, customs, and beliefs), due to which every human being behaves very differently from others given the same event and same built context.

Human response to a built environment includes its perception, the ergonomics of its use, the impact of its intervention within human social systems, and its interpreted meaning. It is probably the most difficult aspect of performance to evaluate and to predict before construction. However, in the final analysis, it is the most important one, because a successful human response to the built environment is the essence of successful design (Steinfeld, 1992).

The research described in this paper aims to partially cover this shortcoming through the development of a computational simulation approach, able to represent the phenomenon of building use associated with specific, ad hoc design solutions. A first implementation of this modeling technique has been focused on representing human behavior in healthcare facilities, using as reference the functioning of a hospital’s nursing ward.

**STATE OF THE ART**

In all design stages it is highly important to fully understand how the future building will be used and the its related interaction with its intended users. Despite this importance, few methods exist that can predict and help to evaluate this type of building performance during the design process. Currently, the assessment of the use quality of building response to future users’ behavior and well-being is left to the insight and experience of designers, who must use their own, often biased and incomplete knowledge to imagine, try to foresee how the building will be used and felt (Perin, 1972).

Norms and regulations are used to represent, in a generalized way, knowledge about buildings’ human-related performances in the design process. Although dominant and influential (Koutamanis and Mitossi, 1996), the ‘normative approach’ has shown several limitations in its application to architectural design. In many cases, buildings in use do not work as intended. Some of their features perform better, some worse, some differently. Norms are generalizations, and their static and rigid representation of average human behavior are ill-suited to the uniqueness and context-dependence of human-built environment interaction, and to the dynamics of human behavior phenomena.

The increasing power of computing and the introduction of simulation-based approaches in other disciplines related to building design (such as structural or energy engineering), have promoted developments of new methods to predict human behavior in built environments. Although simulation techniques have shown their broad potential when applied to representation of complex systems and phenomena (Martin, 1968; Kalay, 2004), their application to human-building interaction have been limited to representation of only some well-defined aspects of human behavior in buildings, such as pedestrian circulation, fire egress and crowd dynamics. Despite the advancements in such directions, other simulation models aimed to general representation of building use are still missing.
Among different simulation approaches, Agent-Based Modeling is currently the most widely used in research and practice. It is based on single, autonomous, objective-driven behavioral entities called agents, which can make decisions and act appropriately when provided with information concerning the status of the environment surrounding them. However, the Agent-Based modeling paradigm seems to actually fail when applied to the representation of cooperation and collaboration among agents (O’Sullivan and Haklay, 2000), which is the prevalent activity of human behavior.

**EVENT-BASED MODELING**

Looking at the limitations of “pure” agent-based systems, and at contemporary advancement in Artificial Intelligence application in game industry, the research described in this paper aims to provide a different approach to simulating users’ behavior in a building, based on clear representation and simulation of the use processes, rather than on autonomous, sometimes arbitrary behavior of individual agents generated by their own specific set of rules. We call these cooperative processes “Events.”

In our modelling approach, events are a representation of how one or more people interact with a system – in our case a built environment – to reach objectives defined by their specific tasks and objectives.

Similarly to their use in game industries and researches, events in building design can be considered plausible narratives that describe the impact of the built environment on activities and life of future users. They are not a direct prediction of how the people will behave in a future building, but rather a knowledge-base necessary for such prediction, to be modified and adapted by local, specific circumstances. Events can be derived from data gathered during contextual enquiry activities in different ways, such as direct observation of similar, already built cases (POE), previous knowledge formalization, hypotheses reviewed by actors usually involved in such kind of use case, etc.

Combined into sequences, which we call “scenarios,” events are representations of the phenomenon of buildings-in-use, in terms of discrete activities, involving a number of users, and performed in specific spaces and time. In the formalization of a scenario, events can be considered as milestones: entities that are structured and connected to each other in order to represent, step by step, what happens in the building.

The use of events as main entities in modeling the building use process is the core of the proposed representation approach. Our choice to move from objects/agent-centered systems to an events-centered system is crucial and directly related to the objectives of the model, namely - to provide reliable and complete data about building in-use.

**Figure 1**

A scenario represented as sequence of event entities, providing information about actors involved, activities performed, and location in the building.
To formalize events and scenarios, we combine three types of information: who are the users involved in such occurrence (the Actors), what are the tasks they perform (the Activities), and in which physical part of the environment the event occurs (Spaces).

These types of information cannot be simply grouped into structures, because they represent heterogeneous and independent domains of data. Each of them acquires a specific meaning depending on its grouping into the assembly. In order to manage these structures of data we have developed the event structure: the three-way, specific combination of Actors, Spaces and Activities (Fig. 1). An event entity provides a specific context that allows the combined Who, What and Where information to be interpreted in a meaningful manner.

Events entities have been formalized by philosophers such as Heidegger (1962) and Kim (1976) as “phenomenological entities” in which are present both abstract, ontological meanings and concrete existences generated by their effective occurrence.

In post-occupancy evaluation processes, events are easily recognized: they are a direct consequence of single users’ behavior, guided by their personal tasks and objectives, composed by a complex system of decision/action processes in order to achieve such objectives in a continuous process of affecting and being affected by the environment and by other users’ behavior. For instance, if some people plan to sit down around a table, each of them will observe the table and the other people’s behavior, evaluate them and then choose their own chair, which in turn influences the other people’s behavior.

Agent-based modeling has focused on the computation of such process of decision/action. Although extremely powerful in theory, it is incapable of dealing with the difficulty of representing such group-cognitive and collaborative decision-making processes in a reliable way. Consequently, all its applications in the field of building design have been limited to very specific aspects of behavior (such as in fire egress simulation), in order to reduce the amount of complex “reasoning” necessary for each actor/agent. None involve complex group decisions, where a representation of human spatial behavior needs to comprise not only single actor’s actions, but also cooperation and collaboration among different people. In principle, this can be done using an agent-based system, but this would be an extremely hard task and far exceed the purpose of our simulation, as each agent will need to process, in real time, the impact of its actions on other agents, read their reactions, and re-process its own actions, etc.

Our approach circumvents this problem by taking advantage of the virtuality of the simulation: whereas in the real world, intelligence is province of humans alone, in a virtual world simulation we can assign computing intelligence also to non-human entities, such as events. Hence we can equip with AI (artificial Intelligence) not only actors, but also the events entities themselves, and assigning them direct control over all the objects (actors, spaces, furniture etc.) of which each event is comprised, during the specific time of occurrence. The advantage of using this virtuality feature is the possibility to build a higher level of computing to control the coherence of the simulation of use process, and to overlap it to a light agent-based system (Fig. 2), in which agents have AI tasks related only to some local aspects of behavior, such as path-finding, obstacles avoiding, events triggering.

The event entity behaves like a sort of movie director, managing and coordinating single agents/actors behavior during a scene, but leaving to them a low level of adaptation (interpretation) to such direction. Returning to the example of a meeting around a table, in our approach there will be an event entity, called “people meeting in a conference room”, which takes control of the actors involved, evaluates their status and the status of other objects in the built environment, and defines each actor’s behavior.

As a matter of fact, this reduction of complexity into manageable chunks leads to less individuality and less arbitrariness of single behavior, but we consider this limitation acceptable for a simulation of a building use scenario. In the sense that rather than looking for a representation of all the complexity of
the real world, our aim is to predict the mutual influence between a design solution of a built environment, and specific, well-defined use case scenarios. At the same time, some degree of adaptation of the phenomenon is still provided using multiple choices inside events, multiple events’ paths and also some local agents’ decisions in order to actually see how the use scenario will ‘fit’ in the built environment. Furthermore, as already shown by research in game industries, event-based model does not have to be considered as an alternative to agent-based systems, but as a possible augmentation of them. The balance between agent and simulation depends on the purpose of the simulation, and on the necessary degree of autonomy of actors involved.

**SIMULATION CONCEPTUAL MODEL**

A simulation model is essentially a system state-generator. It consists of two prime components (Haylor 1969):

1. A static component that represents the state of the system, including all the entities that comprise the system (objects, actors, spaces and their exogenous and endogenous variables), and the relationships among them;

2. A dynamic component that represents changes (how the system moves from one state to another). It is where the system is activated: where the simulation algorithms are run, generating changes in the states of the objects. This component is typically associated with a visualization mechanism.
According to such structure, the proposed model consists of two parts, a knowledge base to provide hypotheses about both use scenario and built environment, and a simulation environment to actually simulate use phenomena (Fig. 3).

The knowledge base represents data and concepts about the system of entities comprising the building (spaces, building components, furniture, equipments); the people who will populate it (workers, visitors) and the process of use (events and scenarios).

Each entity is defined by a specific set of property slots representing its attributes and its status, and by a set of relational rules that expresses its influence and interdependence with other entities. We build and manage this knowledge base by means of ontologies. The choice of an ontological model gives us the possibility of representing all the different heterogeneous entity classes (scenario, events, objects) in a homogeneous form, and to make explicit all the related semantic and the relations among them. In addition, the ontology-based system allows for the creation of specific instances with property specific values, defining discrete objects and connecting them to the simulation level. To build the knowledge base and represent this semantics, we have chosen to use the ontology modelling system Protégé, a Java-based open source ontology editor and knowledge-base framework (Fig. 4).

The simulation environment is where the process of use is actually computed, simulated, and visualized. Inspired by the latest advancements in the video game industry, we chose to use a game engine for this purpose.

A game engine consists of two parts: a 3D graphics simulator, and a manager level for entities and behaviors: the first part defines the place where the entities (people, building and all the physical objects) are graphically represented in a 3D space where we can observe the objects’ dynamics (people’s behavior, objects’ movements and transformations, etc.) while the simulation is running. The second part is where entities’ and behaviors’ data and scripts, necessary to actually run the simulation, are allocated. In this component of the game engine, each entity is associated with a system of property slots and related values that will be changed and updated in real time during the simulation. For in-

Figure 4
Scenario and events representation by means of ontologies in Protégé.
stance, if a person is moving through a corridor, his spatial coordinates and speed properties will vary at each time frame.

To represent and visualize the users and their activities in a 3D simulation environment we chose Virtools, a video game engine developed by Dassault Systèmes, integrated with compatible Artificial Intelligence libraries. Like other game engines, it is designed for fast rendering, and can represent dynamic activities and embedded intelligence in the moving objects, which can be made context-dependent (Fig. 5).

HOSPITAL WARD CASE STUDY
To test and validate the proposed approach, a first implementation has been developed using as case study the simulation of the functioning of hospital nursing wards. Their relative complexity on one hand, and their straight-forward, standardized use pattern on the other, make them advantageous for our research, since they provide a comprehensive, and agreed-upon, data set against which the model can be tested. As a first step, a double scenario has been developed in order to test typical activities in a small hospital ward, and the occurrence of an emergency in a random patient’s room. As shown in figure 6, the same use scenario has been later applied to two different space layouts, to test their capacity to improving or hindering operational activities, patients control by nurses, accessibility in case of emergency, etc. [1, 2].

Our research group is currently applying the same approach to other hospital departments under construction. A use scenario is being developed by means of data collection in similar, already-built hospital departments. The objective of this implementation is to simulate the functioning of the future building, and then compare it with its real functioning after its realization.

CONCLUSIONS
The research described in this paper aims to develop a simulative approach to predict how a building will affect and be affected by future users’ behavior and activities. At the core of this simulation is a clear definition and representation of a use scenario, an operational narrative which represent the step-by-step performing of activities in a built environment.
These adaptive narratives are built using events entities, provided with distributed AI engines, controlling actors’ behavior during the simulation.

This approach reduces representation complexity of human behavior and limits the emergence phenomenon, limitations we consider acceptable for the purpose of our research. The proposed model offers a more manageable and coherent representation of modalities of mutual affection between building environment and its future use (and users). At the same time, it allows representation of cooperation and collaboration among different people who use the building.

Predicting if and how a building will match its intended process of use before its actual construction will have a positive impact on the design process. It will allow designers to evaluate this kind of building performance and, if necessary, to intervene to solve emergent usability problems, critical points and inconsistencies. In the same way, a better comprehension of specific building use phenomenon will give designers the possibility to provide and directly evaluate different solutions, improving quality and liveability of the final product.

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