Simulating Human Behavior in (Un)Built Environments: Using an Actor Profiling Method

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Abstract—This paper addresses the shortcomings of architectural computation tools in representing human behavior in built environments, prior to construction and occupancy of those environments. Evaluating whether a design fits the needs of its future users is currently done solely post construction, or is based on the knowledge and intuition of the designer. This issue is of high importance when designing complex buildings such as hospitals, where the quality of treatment as well as patient and staff satisfaction are of major concern. Existing computational pre-occupancy human behavior evaluation methods are geared mainly to test ergonomic issues, such as wheelchair accessibility, emergency egress, etc. As such, they rely on Agent Based Modeling (ABM) techniques, which emphasize the individual user. Yet we know that most human activities are social, and involve a number of actors working together, which ABM methods cannot handle. Therefore, we present an event-based model that manages the interaction between multiple *Actors, Spaces,* and *Activities*, to describe dynamically how people use spaces. This approach requires expanding the computational representation of *Actors* beyond their physical description, to include psychological, social, cultural, and other parameters. The model presented in this paper includes cognitive abilities and rules that describe the response of actors to their physical and social surroundings, based on the actors' internal status. The model has been applied in a simulation of hospital wards, and showed adaptability to a wide variety of situated behaviors and interactions.

Keywords—Agent based modeling, architectural design evaluation, event modeling, human behavior simulation, spatial cognition.

I. INTRODUCTION

ARCHITECTS design settings to support different types of activities and human needs. However, compared to other artifacts, buildings are too big and expensive to be prototyped and tested before construction. Computational tools at architects' disposal succeed in representing the building's geometry and structure, materials, energy consumption or light setting. Yet, they fail to convey how the building will be *used* by its future users [1]. This type of evaluation is instead based on the architects' knowledge and intuition.

Post occupancy evaluation (POE) or evidence based design (EBD) methods are used to understand human-environment relationships after a building has been built and occupied [2]-[4]. Though this knowledge may be useful for designing the

next building, it is of little use during the design process of the examined building itself, when design errors could still be identified and fixed. Additionally, unlike some well-defined design aspects such as temperature, lighting or accessibility, whose design follows well-established physical rules; *Building-Use* aspects such as way-finding or socializing are less-well established, and require consideration of a wide range of social, cognitive, and cultural traits that vary for different populations [5]. This issue is especially significant when designing complex buildings, such as hospitals, where a major concern involved in the design process is efficiency and quality of care as well as patient and staff satisfaction.

Representing the way humans use buildings sets a grand challenge [6]. Human behavior is complicated and hard to predict. It is occasionally unexpected or surprising, varies from one person to another and occurs due to multiple reasons and goals [7]. Greater difficulties appear when considering the behavior of multiple users, due to variety of interactions occurring simultaneously between different individuals during different activities; what frequently sets the ground for unexpected conflicts, such as gathering and crowding, queuing or interrupting one's activity.

Taking into account human diversity and multiple interactions during the design phase of buildings poses a major difficulty. There is a limit to what extent designers can use their imagination and experience to predict emerging phenomena in complex designs [8], [9]. In order to overcome this difficulty, we propose a simulation approach that enables the evaluation of how an intended design meets its user needs. This paper expands former work done regarding simulation's goals and system architecture [10], [11], focusing on the *Users* by suggesting a modeling method that provides a rich representation of human diversity and interaction in space, prior to a building construction.

Simulation methods have been proposed to represent human behavior in space. In particular, ABMs describe how people react to their surrounding environment and other agents' behavior. ABMs are frequently used to simulate evacuation patterns [12], traffic behavior and management [13]-[14], or airports passenger flows [15], successfully depicting security problems, schedule delays, driving behaviors or transportation bottlenecks.

A different approach is Event-Based Modeling (EBM), where simulation is driven by described behavior patterns, involving a number of actors, spaces, and activities [16]-[17].

This paper presents an Actor Profiling Model (APM), relying on the EBM approach. We demonstrate the system in a case study involving visitors in a hospital environment, by

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:10, No:12, 2016

depicting various scenarios proposed due to interactions between different actor types and their surrounding setting; leading us to claim that APM can help in representing human-environment relationship.

II. LITERATURE REVIEW

A. Human Behavior in Built Environments

Human behavior can be defined as an emergent phenomenon, constantly shaped according to situated surroundings through time. It is inseparable from both its physical and social settings, as well as the activities enabled to be performed. This connection was well described under the notion of *Being* [18], *Place* [19]-[20], *Sense of Place* [21], space's social and behavioral qualities [22]-[24]. Canter [19] describes this notion by weaving three fields which together enable places to emerge: (a) activities; (b) physical attributes; and (c) conceptions. Conceptions, argues Canter, accommodate different individual experiences towards existing setting; driving different uses of those settings. Following this theory, we claim that representing different user types, along with their different attitudes towards their surroundings and activities, is significant when evaluating a building performance.

B. Simulating Human Behavior

Multi-agent systems have been developed to describe how people behave in built environments. One commonly used type of multi-agent system is the Agent-based model (ABM). Aiming to represent human decision making, agents' architecture has a wide range of characteristics and abilities [25], [26], cognitive needs [27], [28], and beliefs, desires and intentions [30], [31]. The challenge faced by architects is to understand the role the environment plays in human performance and interaction, particularly - how different settings impact human decisions and movement. ABM offers a useful model for addressing this objective, by equipping agents with responsive formalisms to respond to both external and internal changes; and allowing both the environment and the agents to react and change accordingly.

ABM has been used to describe people's flow and interactions, stock-market movements and reactions to organizational methods [32]. ABM simulations are highly effective in depicting selected behavior patterns, such as emergency evacuation, crowding and queuing. However, ABM proved to be limited in describing more complex activity patterns occurring in settings that involve structured activities performed by multiple agents in a collaborative fashion. Although collaborative behaviors are enabled by the agents' abilities to communicate and exchange information, this process is cumbersome in terms of system design and computational efforts. Following this theory, Yan and Kalay [33] demonstrated how agents equipped with cognitive traits can contribute to understanding human responses to changing settings. Using ABM approach, they equipped agents with social and situational awareness, and simulated their (different) behaviors in regard to the presence or absence of a

fountain in Sproul Plaza, at UC Berkeley. Similarly, shopping mall behavior was simulated by Cenani and Çağdaş [34], who provided agents with shopping preferences and social awareness.

C. Event Based Modeling

To address the problem of coordinated group activities Simeone et al. and Kalay, and Schaumann et al. proposed the Event-Based Modeling approach [10], [11], [16], [17]. For the purposes of this approach, Events are defined as computational entities that manage the performance of a specific behavior pattern involving actors, spaces, and activities (Fig. 1). An example is the *"Patient-check"* event, where a doctor and a nurse perform an activity common in hospitals of checking patients: all three actors (doctor, nurse, and patient) must be present at the same place, at the same time, for the purpose of performing a medical activity (as opposed, for instance, to a social activity). Unlike ABM, the EBM approach provide the necessary rules to handle cases were one or more of the actors are absent, taking into account their respective roles in the activity.
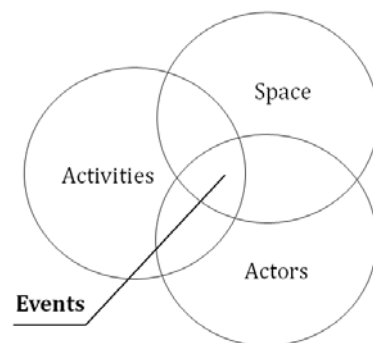

Fig. 1 Event Based Model [8]

The event based model relies on three types of information:

Space

Space represents the spatial locus of activities and interactions. It is defined in terms of *zones*, which describe the function and afforded activities of the space. For instance, a *nurse-station* zone affords patient-record keeping activities, administration, consultation, and communication activities. A section of a *corridor* affords multiple different activities, such as passage and social encounters, as well as medical activities such as patient treatment, if needed. In addition to determining affordable activities, Space can communicate certain parameters ensuing from the performance of an activity within its locus, such as presence of actors and the noise it produces. By doing so, the space construct can be used to replace actor-based perceptual capacities (as done by ABM), and save computational resources.

Activities

Activities comprise the list of actions needed to be completed to achieve a goal. A *Patient-check* event, for example, comprises of activities such arrival of the relevant actors to a specified destination, carrying out the medical

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:10, No:12, 2016

procedure (which involves communication) and recording the results in some form. These lists of activities, which can be sequential or parallel, are communicated by the Event construct to the Actors in a form of a task. Together, all the activities form a *narrative*.

Actors

We consider Actors as dynamic entities that have the ability to move and to perform activities. They have no decision-making or perceptual abilities, because these are provided by the Event which controls them at any given time, as described in the next section. Fig. 2 depicts the actor's relationship with its social and spatial setting, during an activity. As illustrated, the Actor is the recipient of an Activity that needs to be performed, communicated to it by the Event. The performance of the activity is modulated by the Actors current surrounding (physical and social), which is communicated by the Space, and affected by the Actors' internal state (e.g., tiredness). Together, they produce an individual reaction to the Event's directive, which is communicated back to the Event.
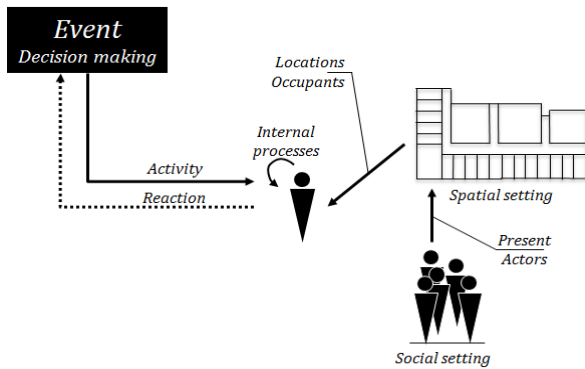

Fig. 2 Actors' relationship to spatial and social setting during an activity

III. ACTOR MODEL

An important component of the EBM is the Actors Profiling Method (APM), which helps to determine if and how activities will be executed, and which modulates their execution based upon and according to the actors' environment and internal state.

People experience internal physiological and psychological changes over time, in response to many interrelating factors. Following Barker's [23] definition of 'Behavioral settings,' which are external to the user, and to the way these settings are experienced and used, we claim that actors not only interact with external settings, but they experience internally the environment, and modulate their response to it whenever they make a decision. For example, the actor's age and degree of fatigue may impact his/her walking pace. A person's fatigue may cause a decrease in the execution of professional skills, leading to bad performance. Accordingly, we construct the APM with categories that describe the Actor's profile and with rules that change its internal status in response to external settings and activities.

The APM is structured as a flexible framework, following two principles: (a) a template of categories and interrelating rules, allowing individual adaptation to different environments and activities; and (b) assigning properties with a parametric range that allow local adjustments to accommodate different populations (in terms of age, gender, profession, etc.). Further, we concentrate on features that can be manifested in observable behavior patterns, including *moving* and *interacting*. We focus on behavioral aspects pertaining to healthcare facilities, as determined by POE and survey research.
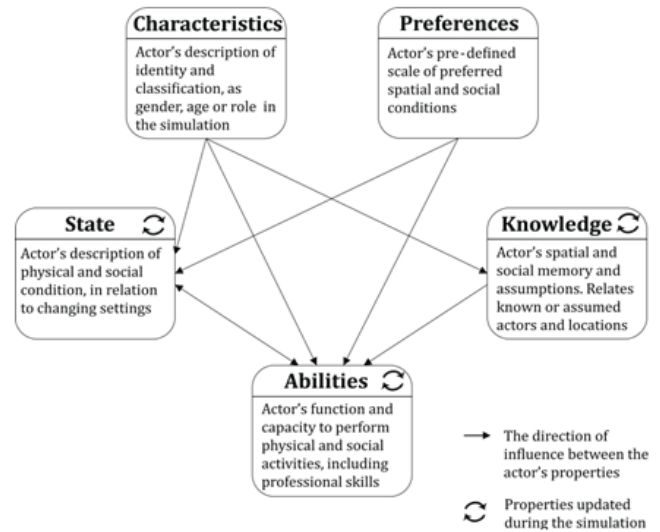

Fig. 3 Actor's data profile and internal processes

Fig. 4 Actor's Profile Template

The APM template consists of five categories, subdivided into static pre-defined categories, such as actors' identity, role or preferences; and dynamic categories that are updated during the simulation run-time, describing the actors' current state and availability to act. Fig. 3 describes the Actors' profile categories and their internal relationships. This approach allows Events to 'pull' information regarding actors' availability to act, which facilitates multi participant Events

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:10, No:12, 2016

management and saves computational resources. A *"Patient-Treatment"* event, for example, involves the patient's state, and the doctor's medical abilities. Fig. 4 demonstrates an example of a Patient's profile properties during the simulation.

A. Characteristics

Each actor has a unique identity, including ID, age, gender and its role in the simulation. Together, these enable Events to manage group activities, assign specific tasks to specific actors, and track actors.

The Actor's role in the organization (i.e. patient, visitor, nurse) stands for its ability to perform some tasks, such as *"assisting patients"*. Depending on their role, actors can also access different parts of the space. For instance, a Visitor type actor cannot access the Nurse station, unless it is explicitly invited to do so.

B. Abilities

Actors are equipped with physical and social abilities. Physical abilities consist of a walkability pace feature, ranging from sleeping to running. Physical abilities depend on the Actor's state of health, fatigue or hunger.

Social abilities relate to the Actor's communication abilities, including talking, leading and informing modes. Talking ability describes actors' availability to initiate or respond to a social encounter. It is triggered by the presence of other actors, and depends on the actor's state of health or sleeping mode. These settings can be used in combination, such as the presence and the degree of familiarity of the actor with other actors, to determine if a social interaction will be initiated.

'Informing' property describes the Actor's knowledge, which can be transferred to another actor. It is dependent on the knowledge stored at each actor.

The Actor's 'leading' property is triggered when the Event involves the Actor in a collaborative activity. It depends on the actor's role and knowledge. For example, a patient can lead another visitor to his room, based on his spatial knowledge. A doctor can lead a *"Doctors-Round"* activity, whereas an intern is not authorized to do so. Actors' hunger and physical disposition may affect this property, causing a leading ability to decrease.

C. Preferences

Humans have diverse interpretations of their environment. Some may accept a noisy environment while others may dislike it. Studies of environmental implications of healthcare facilities on human behavior show a grand variety of factors, including noise levels [35], [36], cleaning and decontamination [38], [39], visibility [40] or crowding [41].

Research found correlation between patient perception of a friendly clinical environment and affordance of visibility, accessibility, path finding and privacy. Notably, findings show that each of these factors was considered to be of different degrees of importance by different individuals [42]. To accommodate this diversity, each actor has a pre-defined scale of preferences; numerically describing how it interprets a given condition. For example, an actor that can tolerate a high

noise level (perhaps due to age) will interpret a 70 dB zone differently than his neighbor who can only tolerate low noise levels; which may lead the second actor to leave the noisy zone. We consider occupancy, light and noise as essential factors to the APM, due to architects' ability to create a meaningful improvement in those settings during the design of a facility. An Actor's preferences impact its state of health, as well as walking and talking abilities. Similarly affected are the staff's professional skills. For example, a doctor or a nurse may have their professional skill level decrease due to personal sensitivity to noise or crowding; leading to different levels of treatment performance. The Actor's preferences are pre-defined and remain unchanged during the simulation. 'Preferences' category in Fig. 4 illustrates the preferences' rate. For example, a low 'Occupancy' rate describes an actor that can tolerate a crowded room.

D. State

The 'State' function describes the actors' changing physical conditions (e.g., health, fatigue, hunger) and current activity (e.g., talking, walking, or sleeping). 'State' is updated by external inputs such as time and distance, or internal inputs derived from the Actor's characteristics, role and abilities (e.g., the Actor's fatigue level can increase due to age or walked distance). In addition, based on findings of Ulrich et al. [43] which relate the environmental implications on the performance of the medical staff, we suggest that actor's state may also affect its ability to perform certain activities. For example, a doctor's fatigue may lead to a decrease in professional skills.
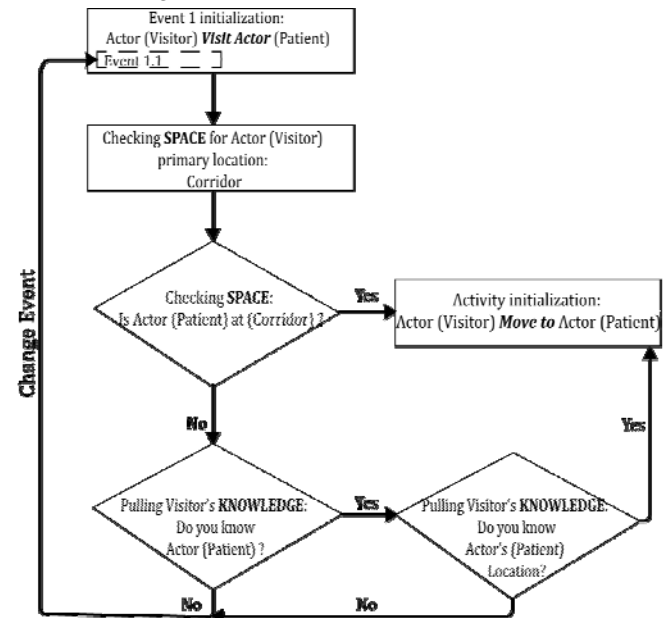
E. Knowledge

Fig. 5 Actor's knowledge attributes' utilization during a visit-patient event, using a hierarchical structure of data pulling rules

Actors are equipped with a list of spatial and social features that describe what they know about existing settings, within the limits of the simulation. This knowledge includes personal

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:10, No:12, 2016

assumptions that can be true or false. They enable the Actor to move and search in the space, given both external settings and individual data. As this data can be partial or untrue, it affects route choices, aided pathfinding abilities, and drives unplanned encounters. For example, an activity such as "Visitor.01-move-to-Patient.01" relies on *Visitor.01* to know *Patient.01's* location. If the Actor does not possess such knowledge, a different event must take place to acquire the requisite knowledge (Fig. 5). These patterns are hard to grasp during the design phase, however they occur frequently in real hospital settings, thus are highly significant when assessing a building performance in terms of way finding or communication.

Spatial cognition studies focus on the way humans use memory and learning abilities to operate in space [44]-[49]. As we strive for representing how people use spaces for the purpose of design improvement, we find these findings significantly essential for modeling actors.

Actors' knowledge attributes address:

(1) Known or assumed spaces' location – this attribute refers to actor's spatial knowledge, attaining a list of spaces, listed with their access location. The list can be modified or grow according to the actor's presence in new spaces.

(2) Known actors – this attribute refers to the actor's social knowledge, attaining other actors' identities, or actor types, or roles

We use actors and zone classification system to host both broad knowledge and a more precise one. For example, A Visitor may possess knowledge regarding an Actor of type Nurse, whereas a Doctor may possess knowledge regarding each nurse's identity in its knowledge list. Similarly, known locations can range from "Patient-Rooms" to "Patient-Room number five".

Actors' knowledge may change and grow due to their activities in the ward, externally updated by Events. For example, a "*Patient-admission*" activity updates the knowledge of the participating nurse with a patient's identity and room location. The participating patient's knowledge is updated with the nurse-station and room location. Further work in this field is needed to understand the limits of actors' knowledge formalisms, defining what it stores and what it forgets, to avoid unnecessary load or storage of irrelevant information.

Prominently, though we acknowledge that many other features may drive human interaction in space, such as human satisfaction or emotional streams, we present a basic framework which can be extended in future developments.

IV. APPLYING THE ACTOR MODEL TO EVENT BASED SIMULATION

The following case studies demonstrate the use of the APM described in this paper in EBM simulation. The simulation in case study A involves a first-time visitor during a "*Visit-Patient*" event, consisting of (a) "*Move-to-patient*" and (b) "*Meeting-patient*" activities. 'Settings' include a simplified hospital ward layout, comprised of several zones (Patient rooms, Corridor, Nurse-Station). When the event is activated, the visitor actor is directed to go to a specified patient (actor P.01) (Fig. 9 (a)). Data pulled from the visitor's profile (Fig. 6 (a), 'Knowledge' category) indicates it has social knowledge of the patient, but no spatial knowledge regarding the patient room location. That leads to activate a sub event "*Get a secretary's information*" (Fig. 9 (b)). The knowledge regarding the secretary's location is stored at the visitor's profile (Fig. 6 (a), 'Knowledge' category), indicating that a secretary is assumed to be located at the nurse station zone, allowing the event to use this information to activate the process. The visitor moves towards the nurse station. When it reaches the target and finds the secretary, the Event activates an "*informing*" activity, involving the visitor, secretary and the nurse-station space. The space tracks weather the secretary is present at the nurse station. The Event pulls the patient's room location from the secretary's profile and updates the visitor's knowledge attributes (Fig. 6 (b), 'Knowledge' category; Fig. 9 (c)). The new knowledge enables the visitor to undertake the "*Move-to-patient*" activity (Fig. 9 (d)). At the patient room, the space seeks present actors, tracks the patient and informs the Event, so a "*Meeting*" event can take place. Both visitor and patient's state switch to a *Talking* mode, which is updated in their state attribute. During the meeting event three other actors enter the room (Fig. 9 (e)). This change in occupancy is traced by the space and informed to both Event and present actors at the room. Due to the change, the Event checks the Actors' preferences rate. Since the visitor and the patient's profiles possess a low occupancy rate (Figs. 6 (b), 8, 'Preferences' category), the event continues. A similar event (case study B) involves an experienced visitor (one who has previously visited the same patient). As seen in Fig. 10 (a), the actor moves straight to the patient's room, since the patient's location is stored in his knowledge list (Fig. 7, 'Knowledge' category). Similarly to the previous case study, three other actors enter the room and traced by the space. This time, the actors are a doctor and two nurses, involved in a "Patient-check" event. The space traces the new event and changes it's semantics to "clinic"; what does not afford the "Visiting" event to continue at the room. Thereby an unplanned event of "*Move to day-room*" is activated. The event searches the patient's state of health and walkability to verify movement ability. The day-room's location is stored at the patient's knowledge attributes (Fig. 8, 'Knowledge' category), enabling the Event to use that information and activate both actors. The visitor and the patient move to the day-room (Fig. 10 (b)).

Figs. 9 and 10 provide a schematic representation of the simulations' results. The simulations were conducted by using Unity 3D software to code event scripts, actor profiles, activities and spatial dynamic conditions. Autodesk's Revit was used for the spatial layout.

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:10, No:12, 2016

Fig. 6 (a) Visitor profile, at the beginning of the simulation, indicating its pre designed parameters

Fig. 6 (b) Visitor profile, during the simulation: Knowledge, Length of stay and State attributes are updated, according to a "visit-patient" event

Fig. 7 Visitor V.03's profile

Fig. 8 Patient P.06's profile

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
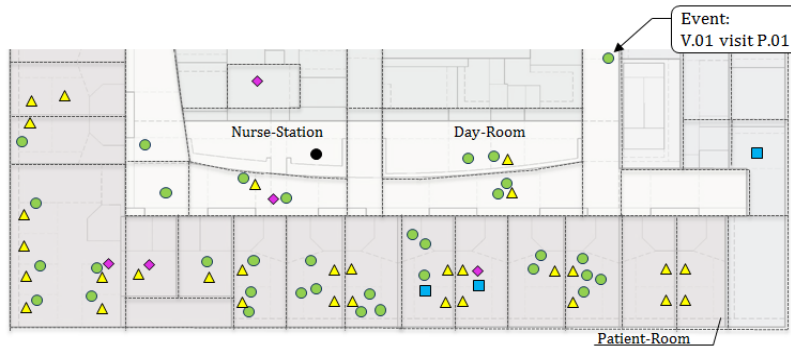Vol:10, No:12, 2016

Case Study A

Fig. 9 (a) Beginning of the simulation. Activating a "*Visit-patient*" event
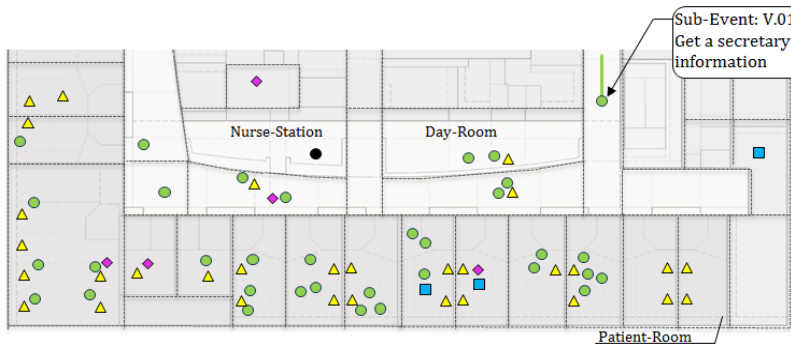

Fig. 9 (b) Changing the destination from patient P.01 to the secretary at the nurse station
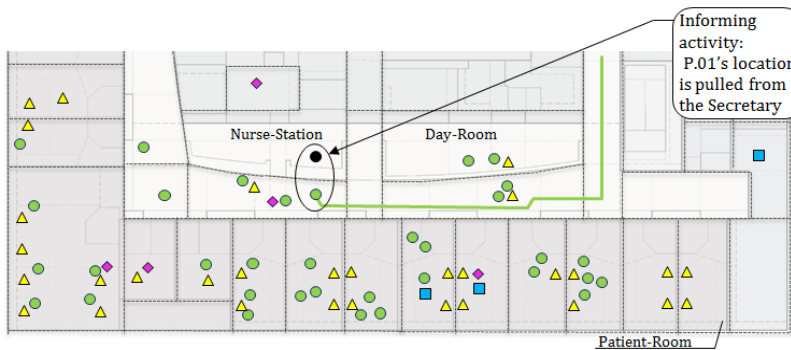

Fig. 9 (c) Informing activity: Getting the patient room's location from the secretary's knowledge attributes
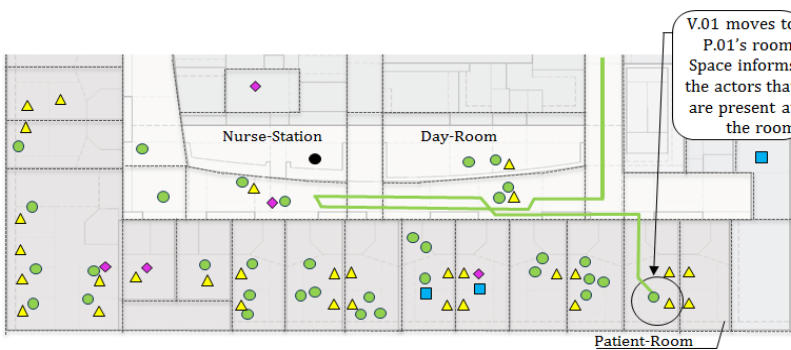

Fig. 9 (d) Reaching the patient and accomplishing the event

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
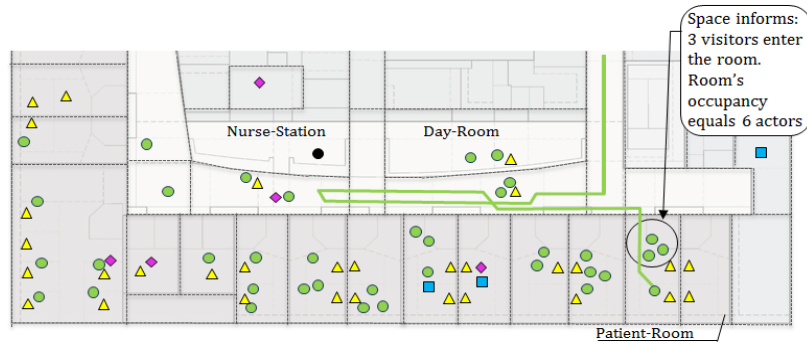Vol:10, No:12, 2016

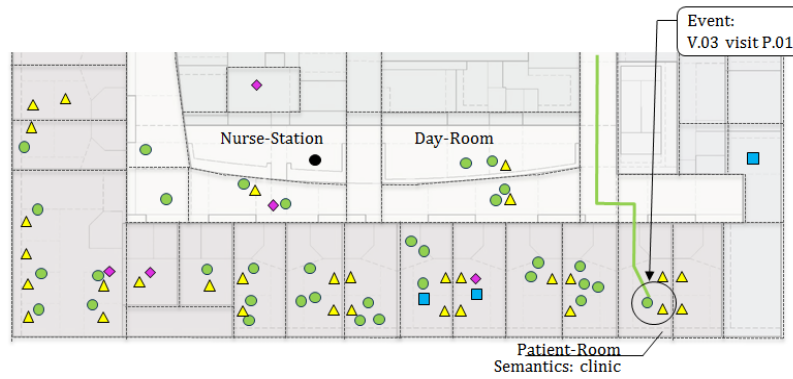Fig. 9 (e) The room's occupancy settings change when three actors enter

Case Study B

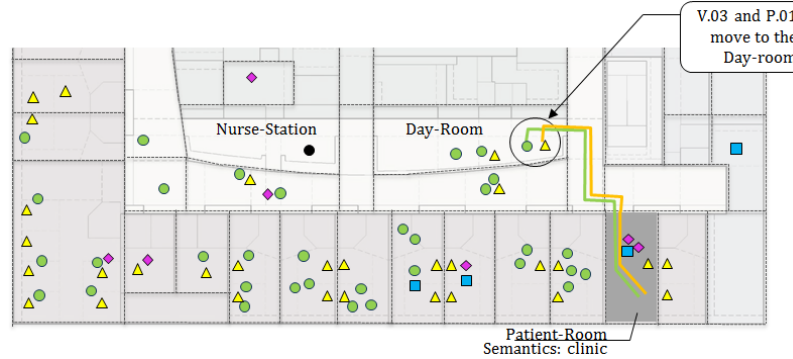Fig. 10 (a) Visitor V.03 arrives directly at the patient's room

Fig. 10 (b) Changing route to the day-room due to the visitor's preferences

Legend

△ Patient
◆ Nurse
■ Doctor
● Secretary
● Visitor
— Patient's path
— Visitor's path

Fig. 11 Legend for Case studies A and B

V. DISCUSSION AND CONCLUSIONS

This paper focuses on adding human behavior simulation to design representation tools. We claim that this missing component is inseparable of the spatial settings that generate a place. The model proposed here is a work in progress. We see this tool's potential in bridging the gap between intended design and its actual use before construction. Our efforts focused on creating a flexible modeling platform that will enable future development of actor entities to suite different designed environments and functions, as well as implementation of additional social and cultural characteristics.

EBM approach enables us to design an expanded Actors model, which describes their cognitive abilities and internal rules of responding to given and evolving situations. Though EBM relies on pre-designed narratives, equipping actors with different preferences and a response system affords a wide

World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:10, No:12, 2016

variety of situated decisions during the simulation and contributes to a richer representation of a building performance. Implementing actors with spatial memory and abilities to communicate it enables the emergence of aided path finding patterns and unplanned social encounters. Further work is required on the actors' profile to enhance their response to the semantics of different spaces, or learning abilities.

A simple case study demonstrates the potential this system holds for foreseeing and evaluating the design of complex environments such as hospitals, train stations or schools, whose design involves many different users.

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