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Performance evaluation of an agent-based occupancy simulation model

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ABSTRACT

Occupancy is an important factor driving building performance. Static and homogeneous occupant schedules, commonly used in building performance simulation, contribute to issues such as performance gaps between simulated and measured energy use in buildings. Stochastic occupancy models have been recently developed and applied to better represent spatial and temporal diversity of occupants in buildings. However, there is very limited evaluation of the usability and accuracy of these models. This study used measured occupancy data from a real office building to evaluate the performance of an agent-based occupancy simulation model: the Occupancy Simulator. The occupancy patterns of various occupant types were first derived from the measured occupant schedule data using statistical analysis. Then the performance of the simulation model was evaluated and verified based on (1) whether the distribution of observed occupancy behavior patterns follows the theoretical ones included in the Occupancy Simulator, and (2) whether the simulator can reproduce a variety of occupancy patterns accurately. Results demonstrated the feasibility of applying the Occupancy Simulator to simulate a range of occupancy presence and movement behaviors for regular types of occupants in office buildings, and to generate stochastic occupant schedules at the room and individual occupant levels for building performance simulation. For future work, model validation is recommended, which includes collecting and using detailed interval occupancy data of all spaces in an office building to validate the simulated occupant schedules from the Occupancy Simulator.

1. Introduction

Occupancy is an important factor driving building performance, and occupants' presence and movement patterns are fundamental to building energy simulation [1,2]. Traditionally, in building performance simulation (BPS), occupancy schedule inputs are static and homogeneous, leading to a lower accuracy in predicting building energy performance [3]. The real occupancy pattern of occupants in buildings may differ significantly from each other [4]. Furthermore, the indeterminacy of occupant behavior in building performance simulation is a leading source of uncertainty in predicting building energy use [5]. To model the influence of human behaviors on building energy consumption and the indoor environment accurately, the occupancy schedule inputs should provide realistic information on the presence and absence status, the number of occupants in rooms, and the diversity of occupant behavior patterns. This issue of realistic representation of occupancy schedules used in building performance simulation has been a recent topic of study and discussion.

Compared to the conventional static schedules, stochastic occupancy simulation models, which better represent the random nature of occupant presence and movement behavior, are recommended for application in BPS programs [6]. The most common way of generating a stochastic occupant schedule is to reproduce an occupancy pattern using selected occupant profiles and then apply statistical models representing the occupant behavior processes [7]. Page et al. proposed a probabilistic model to predict and simulate occupancy in single-occupancy offices, which generalizes a stochastic model for the occupancy simulation using weekly presence probability statistics and a mobility parameter regarding state change of presence and absence [8]. By considering occupant presence as an inhomogeneous Markov chain, interrupted by occasional periods of long absence, the model generates a time series of the state of presence (absent or present) of each occupant in each

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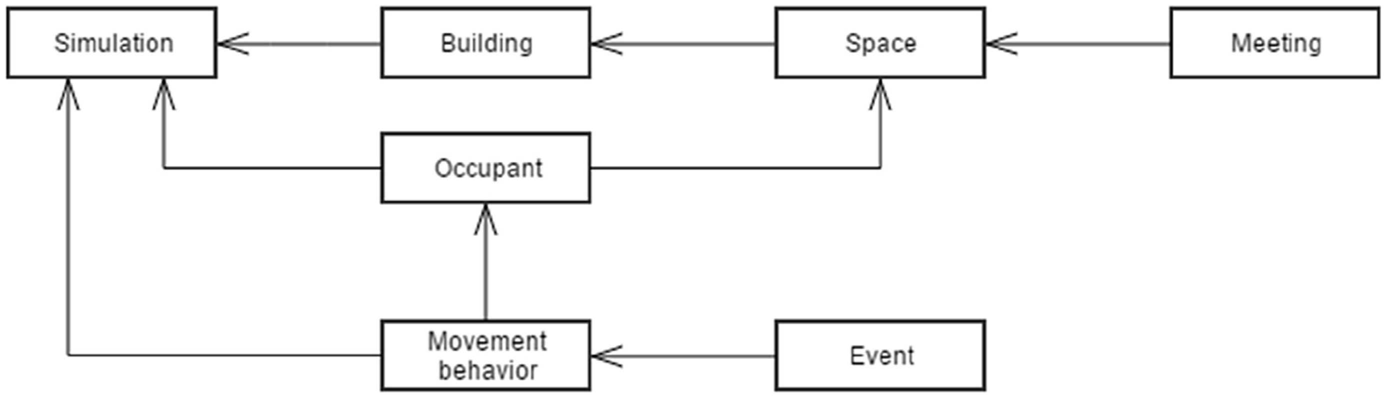

Fig. 1. Object structure of the Occupancy Simulator.

room inside a building. Stoppel et al. also presented a probabilistic occupancy model for occupants' long vacancy activities, which could be further integrated with BPS models [9]. In their simulation results, long vacancy activities such as training, vacation, and other building underutilization are reported in the daily occupancy rates of rooms and buildings.

Incorporating the concept of using occupant profiles and selected properties of occupants to generate corresponding occupancy schedule output, an agent-based building occupancy simulation model based on the homogeneous Markov chain model was introduced to simulate the stochastic movement of occupants [10]. With detailed building and occupant profile as inputs, the model can be integrated in simulation tools to generate time series location for each occupant and the occupancy of each space in the building [11]. This agent-based algorithm was adopted in a web-based occupancy simulation tool named the Occupancy Simulator, which simulates the stochastic occupant presence and movement in buildings, capturing the spatial and temporal occupancy diversity [12].

However, these simulation models are usually based on theoretical assumptions and mathematical simplification of occupancy-related behaviors. In the real world, occupancy patterns are diverse and complex [2], and it is important that the building energy model can effectively represent the features of various occupants' behavior in real [13]. Therefore, to generate applicable occupant schedule inputs for BPS, the stochastic occupancy model should be evaluated according to realistic occupancy properties of a variety of typical occupant types. Moreover, it is necessary to verify whether the implementation of the agent-based model is suitable for modeling different simulation scenarios, and to verify if the model satisfies a range of accuracy consistent with the intended applications.

Existing studies adopted a large number of evaluation metrics to assess the performance of the occupancy simulation models to determine the accuracy of simulation results compared to observed ground truth data. A study by Tahmasebi & Mahdavi validated the stochastic realization of occupant profiles as a representation of occupants' presence patterns by comparing the occupancy model outputs with the actual occupancy levels at the building level [14]. To conduct a quantitative evaluation, three statistical metrics are considered, namely mean error, root mean squared error (RMSE), and Jensen–Shannon distance [15]. Similarly, in Mahdavi's research regarding occupancy pattern analysis, a set of specific evaluation statistics was deployed for the comparison of the model performance—such as the cumulative distribution of first arrival time errors, departure time errors, and number of transitions errors [16,17].

The Occupancy Simulator, developed by Lawrence Berkeley National Laboratory and made freely available for public at occupancysimulator.lbl.gov, is a web-based application running on multiple platforms and devices to simulate occupant presence and movement in buildings. It generates hourly or sub-hourly occupant schedules for each space and for individual occupants in CSV files and EnergyPlus IDF files for building performance simulation [18]. Object-oriented design is adopted in the Occupancy Simulator, which represents the objects of building, space, occupant, and their movment behavior in a hierarchical structure (Fig. 1). Each object is modeled mathematically with its properties and behaviors. For example, the movement behavior object is modeled as an aggregation of occupancy-related events. Under the structure, the simulator performs an agent-based simulation for each occupant to produce individual occupancy by generating a time series of occupant locations that renders occupancy-related events such as arrivals, departures, and random movement from one space to another inside the building.

As the model input, the Occupancy Simulator adopts a set of descriptive occupant profiles to reproduce the occupancy patterns for each type of occupant in buildings using the movement behavior simulation model. The profile is formatted based on obXML, an XML schema that standardizes the representation and exchange of occupant behavior models for building performance simulation [19]. In the profile, each *Space* is assigned a *SpaceType*, which defines the occupancy density, occupancy composition and meeting events in the space. Similarly, each *Occupant* has an *OccupantType*, which is defined by the *MovementBehavior* of the occupants. For occupant movement behaviors simulation, the *MovementBehavior* object includes the detailed description of regular occupancy-related events and their properties, such as arrival and departure events, and the percentage of their presence time in each space category (Fig. 2). The profile serves as the model input for the simulation.

The current implementation of the simulation model aims to generate the regular working schedules in office buildings, considering the stochastic nature of the occurrence of occupancy related events. The space- and building-level occupancy schedules are generated by simulating each occupant separately as an agent and then aggregating the produced patterns of presence. Users can choose an individual space or the whole building to visualize or export the simulated occupancy results. Currently, the model simulates regular work days, while handling public holidays at the building level. It does not yet consider individual long-term absences (e.g. sick leaves, vacations, work from home, business trips, etc.).

This study aims to evaluate and verify the algorithms