Development of a library for building surface layout simulator

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Abstract. Available building simulation tools resort to using fixed schedules for modeling occupant behavior (OB), which does not accurately capture its nature. A significant aspect of OB is the movement, and sequence of actions with regards to their surroundings. This requires some coherence about the surface layout, including the placement of furniture, and the occupant's interaction with it. There is a need of understanding vital information about the different attributes of the furniture, such as the placement, order of importance etc. Until now, there exists no such library with this kind of granularity in information. This paper explores the questions with regards to the development of such a library. This includes the description of the type of variables associated with different kinds of furniture, along with the occupant interaction under typical scenarios. The results from this study can be used to integrate the resulting library with building simulation tools, to better understand and develop occupant behavior models.

Keywords: Building performance simulation, Occupant behavior, Data mining, Building energy management

1 INTRODUCTION

Global energy trends have indicated building energy consumption to be emerging as one of the most energy-intensive sectors, with more than 55% of the global electricity usage belonging to commercial and residential buildings [9]. Recent reports estimate this sector being responsible for 39% and 40% of the nationwide energy consumption in the U.S. and EU countries respectively [15]. Several efforts have been directed to increase energy efficiency in buildings in the form of incentives, certification programs, building codes etc., but despite the advent of these efforts, buildings continue to show a large variation in their consumption patterns, with respect to the expected performance [2] [12].

This performance gap can be attributed to several different causes, pertaining to the mechanical and electrical faults within the buildings, to the weather and climatic variations, or architectural design [14]. However, the past decade has seen a lot of research efforts focus on one particular aspect; occupant behavior (OB). Through the efforts of several global researchers and scientists in the 'Energy in Buildings and Communities (EBC)' program of the International Energy Agency (IEA), the way occupants interact with the building systems has been identified as one of the major drivers of a building's energy performance [16]. Clevenger et al. demonstrated that occupant behavior could vary the total energy use by 150% for commercial buildings [5]. Hong et al. created different occupant profiles and ran building energy models. The authors found that occupant behavior can save up to 50% of current energy use levels, or increase them by 89% [8]. One particular approach to tackle this issue is using Building Performance Simulation (BPS) programs to efficiently improve the design and operation of buildings. These programs include the modeling and evaluation of different systems in buildings, such as thermal or electrical, and are vital for drafting energy-saving recommendations [17]. Even so, BPS programs often lack accurate OB models, with most of the traditional BPS tools using fixed or pre-loaded schedules [13].

Within the field of OB modeling, the current simulation strategies can be broadly classified into two different groups. The first one comprises of models that focus on the systems that the occupant is interacting with, rather than directly with the occupant. These would include linear regressions [18], sub-hourly occupancy-based control models [3] etc. The second group of models deals directly with the occupant and their actions, making use of Agent-Based Models [1], and Markov Chains [10]. However, the application of these models is often limited to one particular function (e.g. window-opening, lighting control). In addition, their dependence on an aggregated model ignores the diversity and inhibits the accuracy in simulating the OB.

OB modeling has its complications based in the diverse set of actions as well the different aspects of the OB itself. The complexity and uncertainty in this field stem from the fact that OB contains various similitudes in the form of presence, movement, activity level, comfort level, social influences etc., and detailed attention has to be given to each of these in order to construct a complete individual profile. Dziedzic et al. proposed a bottom-up approach wherein the collected data from these different fields of simulations could be used to eventually develop a Building Occupant Transient Agent-Based Model (BOT-ABM) [7].

A large part of simulating OB is modeling the indoor movement and transition of the occupant. Markov chains were used by Wang et al. [4] wherein the movement process was simulated by associating each occupant with a homogeneous Markov matrix. A different form of data collection was used by Martani et al. where the Wi-Fi connections were used as proxy for the occupant sensing [11]. Similar to the occupant monitoring and data collection, this comes with its own set of privacy concerns. To overcome those, another study used a depth registration camera to track and monitor the movement and presence while maintaining a sufficient amount of privacy [6].

A complementary aspect in consideration with the modeling of movement is the simulation of the floor surface layout and the placement of objects/furniture around the occupant. In order to accomplish these simulations, the surface simulator will need access to a database or library of specific information regarding the furniture, as well as the details of the occupant's interaction with it. Current literature does not contain any particular specifications that can support a surface simulator with that kind of a database. This will have to include the information about the order of importance of the object for the occupant, their access points, area of influence, placement criteria for each, amongst others. The necessity of this information arises from the need to understand the boundaries and potential paths for the occupants' movement, as well as their order of actions with the objects around them. The next section describes the development of this database, definition, and properties of each variable, and their necessity for the simulator.

2 DATABASE DESCRIPTION

The library is intended to provide necessary information about the furniture and its placement, to be used for a floor surface layout. The furniture would be the ones typically used in residential buildings, and will consist of different variables associated with each object, the information about which will be determined by collecting data from the occupants themselves. Each variable is selected based on its connection to the way the object influences or hinders the actions of the occupant with regards to their location and movement. The description of each of those is as follows:

- FurnitureClass: This variable contains the description regarding the type of furniture. The different classes will be procured from a compiled list of the typical furniture used in different rooms.
- RoomCategory: Represents the type of room (bedroom, living room etc.). This variable would further influence the OrderOfImportance, since the objects having the same FurnitureClass can have different significance depending on the RoomCategory. For instance, the order would be different for a table in a study (where it might be prioritized higher), and in a bedroom (where its importance will be relatively lower).
- OrderOfImportance: This variable describes the order of the object's importance to the occupant based on the frequency of use within a particular room category. It also indicates the rank of this furniture when it comes to the placement. The simulator will be using the allotted ranks to generate the sequence of each simulated object within the room. This will have to work in accordance with the next variable,

wherein objects with higher rank will be prioritized and placed according to their PlacementCriteria, and those criteria will be re-evaluated for the next object, without disturbing the placement of the preceding object.

- PlacementCriteria: This will ascertain the typical factors that influence the occupant while placing the furniture with reference to the distance from the corners, edges, doors, windows etc. The information will be significant in generating a surface layout based on the floor map of the rooms, and will further ease modeling the path of movement that the occupant will be taking. It will also enhance understanding about the intent behind the occupant's actions, and these preferences can also be used as input for building habit profiles for the occupant.
- AreaOfInfluence: This variable reflects what kinds of constraints and influences the particular furniture creates for the occupants' movement around them. It also constitutes how it affects the placement of the other objects. Along with hinge points, this serves as a decisive factor for the path simulation.
- AccessPoints: The position respective to the object through which the occupant would be interacting with a particular FurnitureClass.
- HingePoints: These points would indicate the corners or edges of the furniture, and will form the basis for movement simulation, as the distances from different hinge points will reflect a range of the potential path the occupant could take.

The following table (Table 1) consists of the seven different but interconnected variables for the database and is meant to showcase how the library is structured. Variables like these will be necessary to act as trigger points for further actions, and as specified for some of them, the use of them goes beyond floor surface simulation. One instance of this is the placement of outlets for the HVAC design. Better surface layout simulations can help adjust the outlet placement in accordance with the occupant's thermal comfort needs and their surroundings.

Table 1. Variables to be used in the database

Furniture Class	Room Category	Order Of Importance	Placement Criteria	Area Of Influence	Access Points	Hinge Points
	1		Criteria1			
Class1	2		Criteria2			
	3		Criteria3			
	1		Criteria1			
Class2	2		Criteria2			
	3		Criteria3			

3 PRELIMINARY SURVEY

The survey to gather the necessary input from occupants to create an adequate database was designated to be set in an online format. The main factor responsible for the design format was the need for different possible combinations and scenarios with regards to the occupants' preferences. The database needed a large number of layout preferences while keeping the models realistic by using different constraints. It would be extremely difficult to accomplish this using the traditional experimental data collection platforms. Fortunately, the advent of Massive Online Experiments (MOEs) has made possible conducting studies with large scale participation, an exponential combination of different variables, while retaining the control on the experimenter's side. These web-based experiments provide specific advantages over the lab-based ones in terms of collecting larger sample sets at a much lower cost.

Additionally, the main requirement of this study was to have sufficient features that enable the occupant to assemble their own layout, and provide feedback regarding that preference, which is possible through these MOEs. The development platform chosen for this was Meteor, because of the template based structure it offered, in addition to its useful packages and dynamic scripting.

However, a preliminary survey was conducted to test out the feasibility of the concept and gather feedback from the occupants. The survey was designed to investigate the home space usage of kitchens in residential buildings. The scope was to seek out information regarding the different kitchen appliances, and how they are placed around by the occupants. This was done to generate a sufficient database for a kitchen layout simulator. It explored the number of occupants and their demographics. These occupants were then provided with a questionnaire along with a list of typical appliances found in a kitchen, with the option to add any that were not present in the compilation.

The RoomCategory in this case would remain fixed, as the study was still in its preliminary stages and wouldn't extend beyond the kitchen. There were in total 18 FurnitureClasses in the compiled list provided, for the participants to choose from (Figure 1). The occupants had to denote the presence of the appliance and provide the OrderOfImportance for each. In addition, they were also asked to mark down the position of windows, doors, orientation, and the approximate shape of the kitchen. In order to have better insights, they were asked to mark down this information on a grid, as shown in Figure 2.

The collected information would then be used to generate appropriate hinge points to determine the movement path. Other variables such as the area of influences and placement criteria were not added at that stage. They were to be approximated based on the layout given, but later added in the main questionnaire to remove the need for any assumptions. It was due to the ease of incorporating the feature of having a base layout that can be modified by the participants that the choice was made to shift the process online.

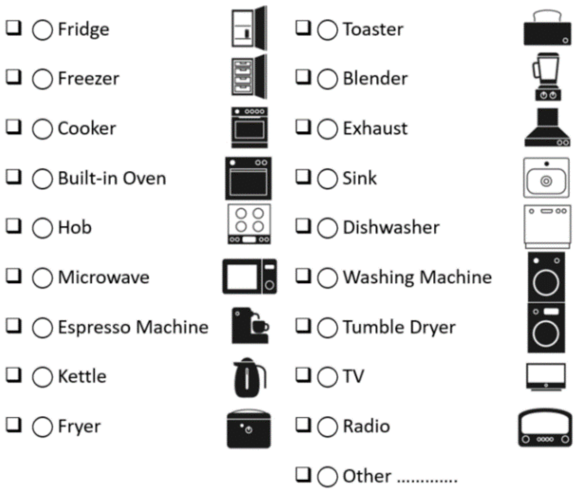

Figure 2. Compilation of Furniture Class

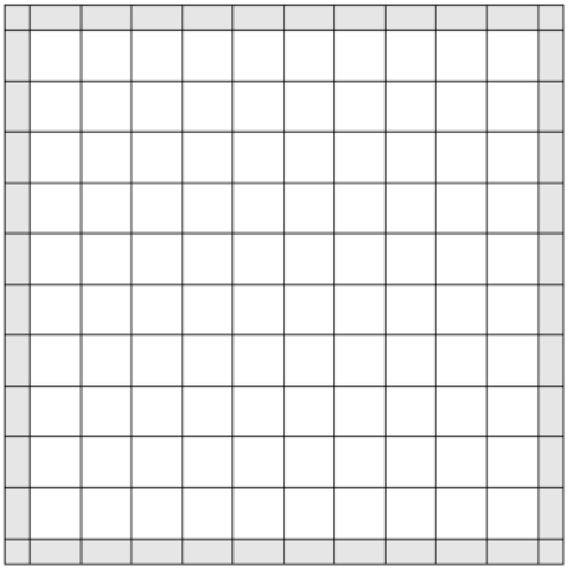

Figure 1. Grid to record layout and preferences

4 DISCUSSION AND CONCLUSION

As seen from the literature review, there is still a significant potential for improving building performance simulations through OB modeling. Considering the diverse aspects of OB, this study supports the bottom-up approach and highlights the need to consider a more dynamic process for delivering the surface layout simulation. It should be noted that the primary purpose of this database is to provide a library for the layout simulation. Furthermore, the layout simulator is intended to act as a building component for an eventual BOT-ABM.

As mentioned previously, some of the variables can prove useful for other purposes, such as HVAC design. However, that is beyond the scope of this particular study. Future research can be directed towards incorporating this kind of a database and surface simulator in traditional BPS programs.

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