Framework for a transient energy-related occupant behaviour agent-based model.

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Abstract. Simulation of occupant behaviour (OB) is a topic considered to be crucial for further advancement in building performance simulation (BPS). Previous (statistical and stochastic) approaches in attempting to re-create in-building human activities were not sufficient to capture subtle activity changes with significant influence on building energy performance. Development of an occupant behaviour agent-based model seems to be a promising direction because such an approach allows deploying a time-dependent, reactive model. The main purpose of the agent will be its presence in the simulated thermal environment and its ability to react once the thermal conditions are outside its established thermal comfort zone. Herein, the agent model has to provide a personification of its thermal comfort condition. To introduce such features for OB simulations in BPS, a new model framework was introduced. It will enable probing of the simulated state of thermal conditions and the "sensing" of it. If conditions are inside the required limits of thermal comfort, the agent will not react. Otherwise, if the state of the agent's thermal comfort crosses its threshold values, it will try to adjust its thermal conditions using local adjustment possibilities, e.g. simulated adjustment of the set-point. The fundamental input data for this agent model can be obtained by use of the depth registration camera for direct observation of occupants. Continued monitoring of occupant reactions in various thermal conditions will be a foundation for the development of the occupants' thermal profiles. Storage and compilation of such information will contribute to the detection of the parameters that are mandatory for the development of the transient energy-related occupant behaviour agent-based model.

1 Introduction

According to the newest International Energy Agency annual report, thirty per cent of the globally produced energy is consumed in buildings [1]. A vast portion of this resource is explicitly consumed to match up with the expectation of its users. For the past forty years, researchers have investigated demand and the way the users exhaust energy. During that time, the topic has become mature enough to be considered a separate branch of scientific field related to the understanding of building energy performance. One of the milestones in the field of occupant behaviour studies was a work presented by Fanger [2]. His work on the presented ideas and application proposition initialised the process of describing human interactions with the indoor environment. Still, due to the multidisciplinary nature of energy-related occupant behaviour studies, it is difficult to develop a model that could apply to any and all conditions. Similar obstacles appear when it comes to a simulation of the different types of buildings. Lack of accuracy in existing models was noticed and pointed out in the work of Turner et al. [3]. In this, a comparison was made of the energy consumption results from building energy performance simulation and consumption during operation time (after it was built). Comparison have shown that only 30% of investigated buildings consume a similar amount of energy. It is possible to conclude that one of the reasons for such a mismatch is caused by underrating occupant influence on building energy consumption. It seems that the current resolution of monitoring occupant activity is not sufficient to capture energy-meaningful phenomena. The basic description of the occupant as a system user has to be more comprehensive, and it should allow the inclusion of a broader spectrum of occupant/building interaction. Such a conclusion can be made after reviewing Yan et al. [4]. As put forward by Hong et al., ontology is the classification of occupants regarding their energy-related behaviours [5-6]. The approach they present segregates a particular occupant's actions with regard to common behaviours that have influence on building energy performance. Among these are switching on/off the lighting or adjusting windows blinds. Such studies are a step towards transient agent-based modelling wherein a single agent represents the behaviour of one person. However. to gain access to the more comprehensive overview of occupant's actions, it is a necessity to understand their demands and needs. As Wagner et al. notes, this can be done by way of statistical analysis of the group or occupancy state coupled with multi-sensing techniques [7]. Additionally, occupant-related studies should be supported by survey and interviews that allow a description of the personal preference of the particular person. The previously conducted work of Dziedzic et al. shows promising results regarding developing precision in indoor occupant profiling via depth registration camera [8]. A good example of the broad spectrum of data collections was shown in Jamrozik et al. [9]. Herein, collected observations of the human reactions to the thermal environment were enriched by inclusion of occupant socio-psychological data. With such a multidisciplinary approach, it is possible to track occupant motivation for chosen action. A precise socio-psychological description allows compilers to gather, cluster and detect trends among occupant personality. Hence, capturing data holistically regarding energy-related drivers can be used as an additional asset in the development of an action-driven model of occupant behaviour.

Gaetani et al. provide a selection of models that are "fit-to-purpose" in order to show the current developmental level of occupant behaviour modelling [10]. Based on the provided [10], it is possible to notice that most of the developed occupant behaviour models are focused on one or only a few particular issues regarding occupant behaviour. What is also notable is the lack of communication among the model developers and that this has brought about overlaps and absence of cross-modal communication. The idea of "fit-to-purpose" propagates understanding that each application has its optimum workflow resolution, and in the present, there is no solution for scalable applications regarding occupant behaviour modelling. Similar conclusions were drawn in a work of Bing et al. [11]. The main challenge related to occupant behaviour modelling, in general, is operational resolution. Occupant activity that could be considered as significant regarding energy use can be triggered by an event lasting only a few seconds, for example, a draft caused by the sudden opening of a closed door. Yet, exposure to a particular "incident" may have long-term implications, like adjustment of the thermostat. Capturing such phenomena requires a high observational resolution of occupant behaviour. Previously developed models were not capable of portraying such events, because their initial resolution was beyond the ability to capture such an event.

The main disadvantage of any available OB simulators is that all of the spectra of actions are driven by probability or stochastic process. This means that particular occupant activity has no relation to the particular order of performance. Thus, there is a possibility to develop a "story-driven" or "action-reaction" understanding of simulated actions. This has come about by the input data for which previous models were compiled. The origins of limitations within previously developed models were engendered by the resolution of the data that they developed. Current models are capable of performing well on simulations that involve a group of occupants, such as shared lunch, or general occupancy of a room. Unfortunately, trying to identify a reason, meaning or driver of connected actions at the individual scale is impossible from such simulation results. Therefore, the actions triggers are also unknown. To fulfil all of this uncertainties, it is necessary to re-develop occupant behaviour models so that it is possible to explore the reasoning for a particular action. To reach all of the expectation regarding model features, the need is to develop an agent-based model. Here, the simulated agent represents an occupant and it is equipped with an embedded complex behavioural engine capable of simulating reactions to the various conditions of the indoor environment.

The main aim of this paper is to highlight the core milestones of the model development process. Due to the complex structure of the proposed, developed solution, it is necessary to highlight potential outcomes and to open dialogue with the broader scientific community. The proposed framework of the model does not aim at the promotion of particular software or application. This work aims only to introduce to the wider audience, the possible structure for simulation of indoor occupant behaviours.

2 Framework

With regard to heating and cooling, to reach the collective expected requirement that allows generating a contextual response to the simulated actions, the simulated agent has to experience similar thermal conditions. In bringing this about, it is necessary to probe data drawn from the constantly changing physical properties of the indoor environment. This means that the model has to operate on transient indoor environment proprieties. This data can be acquired from a computational fluid dynamics (CFD) simulation or through a multi-zonal model. Because both of the simulation methods consume a significant amount of computational time (at least for now), it is recommended to perform a series of parametrical studies beforehand. As the simulated occupant behaviour relays on reaction to the on-going environment condition, if environmental and physical properties are pre-simulated and the transition between states kept in order, such properties will not have influence upon the occupant behaviour simulator. This implies that while the environmental conditions will influence the occupant behaviour simulator, the simulated agent will not have influence upon the environment and the conducted actions by the agent will do so. Because this approach is based upon assumed model features, this approach is referred to as the 'building occupant transient agenda-based model' (BOT-ABM). The purpose of the model is to simulate more realistically the usage of the various energy resources. The agent (i.e. the simulated occupant) is brought into being by a collection of modules that re-create the routine activity of the building users. Herein, each individual module is responsible for the simulation of one specific behavioural feature. Moreover, all of the used modules operate in the same temporal resolution, and the general model architecture is designed in a parallel structure. As the solving of one particular time step will require the calculation of each activated module, this will increase the calculation time of each

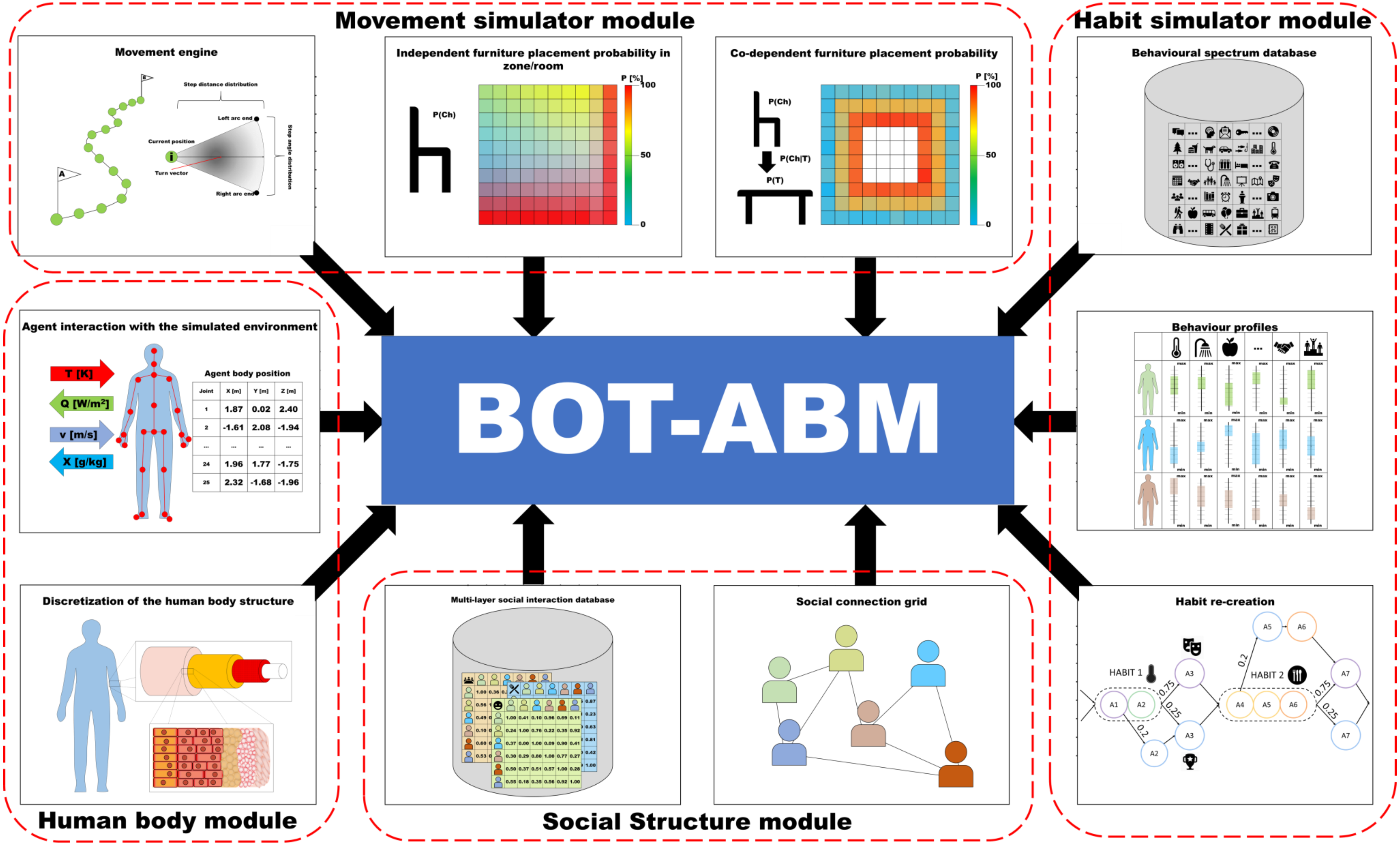

Fig. 1. Building occupant transient agent-based model

time step, but it will allow cross-communication between each of modules. Such a structure enables the development of co-depended scenarios where one particular phenomenon, such as spontaneous exposure to a cold draft, might generate a variety of BOT-ABM reactions. The general structure of this in the form of an information flow chart is presented in Figure 1. Individual module functionality will be briefly explained

3 Modules

3.1 Movement simulator module

One essential feature of occupant activity is the ability to move around. Nevertheless, this occupant behaviour feature is not explored enough with regard to applicability in building performance simulations. In doing so, however, the simulation of direct movement will require a radical incrementation of the time resolution, which, subsequently, will increase required computational power need.

In contrast, simulation of all the transitions allows a precisely described occupant exposure to the indoor environment. It green lights the gathering of data about the occupant position in time; therefore it allows implementing the module that simulates interaction with an indoor environment. The full probing of environmental data will be brought about through the collective response of individual models. This part of the model provides for discretised positioning and transition of the human body, in time.

The Movement engine module itself is solely responsible for simulating the natural transition between point A and B. It will operate through any defined polygon, but to re-create realistic usage of the building, it has to operate within a furnished layout. Once the floor layout is fully designed, the simulated agent actions will be relayed to general placement. Herein, the furniture setting will be used as a coordinate system for the agent movement. The agent will then perform the intended performance task, and will operate and interact with appliance in the same manner as would the building occupants. Data from such appliance usage could be collected via analyses of the plug load or through various Application Programming Interfaces (API). If the layout simulator is available, it will be possible to simulate the layout scenarios, to test various scenarios and to investigate which is producing the most energy efficient or most comfortable settings. Furthermore, it may allow testing how floor layout operational changes (like adding an extra, internal wall) may influence indoor air conditions.

Development of the layout generator has to be paired with the development of an extensive library of appliances and furniture designed for this purpose. This dataset has to hold information about appliance dimensions, heat map localisation (probability of the placement on a floor layout), potential activities that it may be used for and the zone wherein it is possible to interact within. All of these features are important for precise simulation of the building occupant activity. Appliance dimensions (Length, Height, Depth) and heat map localisation will be used for appliance placement in a simulated layout, and for development of the geometry for final operational air volume. If the study is aiming at a parametrical analysis, the heat map localisation feature will not be used. The list of potential occupant activities will be employed to enable a description of the appliance/furniture purpose, as well as to support the habit simulator and the physical environment sensing module. If the agent has to initialise an action, for example: prepare a meal, there are only a few appliance s that can support the execution of this task. The agent will be instructed to select one of the given options and fulfil the given "task/need". Once the procedure of appliance selection is done, the agent will find a pathway from its current position to the aimed goal which is the space/area where is possible to for interact to occur.

3.2 Habit simulator module

The purpose of the habit simulator module is to trigger activity. This module will cover most of the essential description of agent personalities and their way of utilizing the space. Description of agent habits will cover a wide range of activities connected with maintaining a portrait of occupant routine and of related activities. Additionally, it will try to include a possible spectrum of irregular activities that are non-explainable or could be considerate as unreasonable. This module will be designed to operate within three separate layers: Behavioural Spectrum, Behaviour Profiles and Habit Re-creation.

The first layer (Behavioural spectrum database) will be used as general database source-set of potential activities. This database will deliver operational space for a selection of various behaviours. Thus, it serves as a pool of possible outcomes that can be triggered by any given condition at a particular moment. The spectrum and source of triggers may vary. These depend on the given situation – whether a sudden change of conditions or scheduled activity or simulated "loss of interest". The more extensive that this library of activities is, the greater the potential exists to simulate more sophisticated activity. This can be analysed later on so as to improve performance. Every time a simulated action is triggered, it is recorded on a simulation timeline. This activity allows for developing an understanding of the context of each conducted activity. Therefore, it will be possible to analyse simulated occupant behaviour by way of a story-driven method. Such an approach will allow investigating building design that includes sensibility analysis of the potential group of building users, and, hence, an estimate of the potential energy demand that the group may require.

Second layer (Behaviour profiles) will focus on an individualization of the activity, by generating an individual behaviour profile description. Each particular activity has to be described by the following features: the conditions that triggers it, the spectrum object or tool that it has too interact with, the time that is consumed in conducting it, the mechanisms that must be operated, and the gain achieved. All activities have to be segregated into two sub-categories, cumulative sum-based or threshold-based. The functionality of the activities that are cumulative sum-based rely on the fulfilment of the task. Each utilized time unit of the selected task performance increases the cumulative sum. In contrast, threshold-based activities are triggered if the threshold of acceptance of the simulated conditions is crossed. Both of this actions trigger engines that control agent performance. Attributes can be defined by the selected trigger engine and described by its operation values. For example, the simulation may test appropriate occupant reaction on a spectrum of indoor air thermal conditions. If the simulated occupant is "sensing" that the indoor environment is beyond its thermal acceptance level, it will react. Its action will aim at a return to the "comfort" state. To do so, it will have a spectrum of potential actions that will provide a return to the acceptance level of a given condition. To avoid infinite feedback loop, each conducted activity will have a "death band" functionality. Therefore, the simulated agent will be described with a certain acceptance reaction latency.

The simulated behaviour of the agents will require behavioural specification. Each agent has to be described by the constraining values of their "personal" preference with regard to the global "character" description. This part of agent description will be held by the behavioural profile layer (second layer). Here, selection of the "basic" human needs and desires can be transferred from the field of anthropology, wherein the study of human behaviour modelling is a scientific pursuit. Through accessing this branch of natural science, it will be possible to define the fundamental features of occupant needs. The most applicable model that fits into the proposed model structure is that suggested by A.H. Maslow [12]. Pyramidal structure describing Hierarchy of Needs can be used as a template and be explored in terms of its applicability in building performance simulations. The selection of appropriate behavioural (anthropological) model and its modification, however, will not be elaborated upon in this paper. Whatever the anthropological model selected/modified for BOT-ABM performance purposes, all of the features included in the description of occupant profile must be transferred to the Behavioural Spectrum layer of the habit simulator. This procedure will allow for direct communication between all of the layers included in this module.

The third layer (Habit re-creation) of this module will be responsible for a re-creation of occupant habit and daily routine. By way of applying this part of the module, it is possible to simulate a task that can be considered as mandatory, such as going to work or school. Proper usage of this layer will allow to control agent health maintenance and the strategies that are triggered by occupant activities related to hygiene and healthcare. It must be noted that each individual has a routine – a daily rhythm and way of organizing daily activity. The order of the actions taken depends on various conditions like lifestyle, personality or employment. No matter what kind of routine each person follows, the day timeframe limits the amount of actions that person conducts per day. This means that pinpointing this on a timeline and limiting its duration can describe daily activity.

Additionally, as habits are desires expressed through a series of actions, each conducted activity can be considered as being a derivative of habit and routine. The module that is responsible for the re-creation of occupant habit, can be looked upon as a binder for a series of actions. Additionally, as the order in which particular activities are followed plays an important role, this part of the module will hold "recipe" information about each habit. However, BOT-ABM will be designed to follow habit protocols as long as its basic demands, described in the previous layer (Behaviour Profile), are balanced. This layer of the module will keep the agent following a daily routine without pointless wondering in uploaded space, zone or floor layout. It will also allow for tracking the overall understanding of the agent's action purpose.

In attempting habit and routine simulation, there is a vast range of activities that cannot be considered routine or habit. Because their nature is unpredictable, as pointed out by Strengers, there are specific actions that cannot be directly explained [13]. Irregular occupant behaviour is defined as an act wherein the occupant consciously or unconsciously performs an action that does not fit in order or/and timeline of any routine. That is why the core description of conducted actions order cannot be completely fixed - it has to hold space for potential irregularity. To do so, all of the daily routines have to be described via a probability factor. This function is responsible for the scoring of the action inside one routine, regarding holding its order and timeline coherency. The higher the value of this probability factor, the larger the probability of habit re-creation inside the simulation.

3.3 Social Structure module

To re-create building occupant behaviour, it is necessary to include their interaction with other occupants. No matter what kind of building is being simulated, the existence of the social grid inside it cannot be by-passed. Indeed, its magnitude can be only forgotten if the designed space of investigation concerns one individual. In the other cases, the way occupants interact with each other has to be included in the simulation. This module will hold information about the social connection between agents, and it will be responsible for assessing the degree of potential collaboration between each in various tasks/routines. Here, selection of assignment has to rely on a hierarchy of relationship structures inside the simulated space. It also has to allow for agent collaboration, as well as following the grading system of simulation. Of note, the simulation of occupant social network also depends on building purpose. If the simulation targets a residential building, the social connection must consider family structure.

The data about the social network in the observation space can be captured by way of the use of mobile telephone data streams. As shown by Ren, Ye. et al., this makes it possible to obtain information that allows for re-creating the social communication structure of the monitored occupants [14]. However, a combination of various measurement methods may allow developing a better general understanding of social connections in different types of buildings. Once such a knowledge base is obtained, it may be used automatically to allocate specific social networks to the appropriate buildings. Until then, this has to be done via the use of pre-defended networks and application of hierarchy.

3.4 Human body module

This module is responsible for the positioning of the human body inside the simulation environment. Here, a general projection of the human body can be used to probe data from a selected body part or point of the body. This feature can be used to calculate the radiant temperature of investigated body limb/area or the general exposition to airflow streams. The limitations of the probing depend upon the used simulation environment and the embedded equations. The higher the resolution of the indoor environment simulation, the more detailed the study. To simulate human body reaction, it is also necessary to investigate the kind of processes that are happening inside the body. An excellent example of a model that could be used for this purposes is that proposed by D. Wölki, wherein the human body is divided into nineteen parts, each part being composed of a few layers of the human tissue structure [15]. This approach shows promising results, but it has to be improved in terms of simulation of the tissue composition. The current state-of-the art is that this model assumes uniform tissue distribution. To simplify modelling, uniform tissue distribution can be considered a good approximation, but for detailed study, such an assumption might be crucial. To provide a proper response to the habit simulator, the delivered input information has to be accurate in order to prevent agent misinterpretation. Hence, the more recent MORPHEUS model must be explored and assessed for simulation competence [15].
Besides sensing the environment, this module will be responsible for delivering information about agent activity level, clothing level and the related. Such information is crucial for the proper simulation of the energy-related occupant behaviour in buildings. Knowledge about activity level will support indoor environmental simulation by delivering data dynamics of energy relesed by the human body to the investigated space. Additionally, it will be a marker for a proper re-creation of the pendular movement of agent body parts. Simulation of the clothing will be embedded in the same way. It will provide an overview of skin exposure to the indoor environment, but it will also be charged by the response system from the habit simulator module.

3.5 Information exchange and modules hierarchy

Access to all of the features that are provided thru each separate module requires an understandable architecture of information flow. Without a specific order of hierarchy, a collaboration between modules might produce a chaotic representation of the actions without meaning. Centralised structure of the BOT-ABM allows for modular applicability of the whole model, but whole information exchange is via its centralised mainframe. It can be considered as a historical database of the particular agent.
In presented BOT-ABM structure, two modules (Movement simulator and Human body) are responsible for direct interaction with a physical environment. Therefore, these modules are not producing a “decision” impulse for conducting a task by the agent. Both of these modules operate on two-way communication with a BOT-ABM mainframe, but each of these modules has a low position in a decision hierarchy.
Other two modules are responsible for taking care of socio-psychological side of the occupant behaviour. The proposed model structure is aiming at a simulation of the individual occupant behaviour. Therefore, Habit simulator module will play a critical role in a decision hierarchy. This modules are not responsible for the probing of the data from the environment. They accumulates the collected information from the other modules, uses it as an input and process it with a defined personal trades. Generated output distributes information of an adequate response to the other modules.
Hierarchical position of the social structure module is hard to pinpoint directly. It might have a significant influence on a Habit and Movement simulator modules. It is also used as an information exchange port with other agents, which allows for a mutual collaboration of numerous agents while keeping their individual trades. Because the main aim of the BOT-ABM is to simulate individual occupant behaviours, Social Structure module has the lowest hierarchical position.

4 Discussion

The presented paper provides a brief overview of the occupant behaviour simulator that potentially can be used in ~~a~~ BPS. The proposed solution operates upon four different modules - each responsible for one facet of human activity. The main aim of this model is to re-create inside building occupant behaviour. Due to the diverse operating resolutions of human beings and building structures, it is difficult to assume what kind of time resolution is optimal for simulation purposes. From the perspective of the building user, a one-minute resolution could be considered too shallow for portraying their behaviour correctly. On the other hand, same resolution can be considered as too detailed if the perspective is set as annual building operation. Therefore, it is difficult to decide what kind of time discretisation should be acceptable to portray events that could be considered as important from the perspective of the building user. Still, no matter what kind of operational resolution will be selected, the proposed structure allows exploring occupant behaviour phenomena through a multi-disciplinary approach.

Social structure can equally influence building user behaviour as does the sensation of thermal comfort. Therefore, the impact of this attribute cannot be ignored, but there are no available tools that allow for a numerical investigation of such. To by-pass, this issue, the proposed framework introduces a modular model structure that allows for non-invasive editing of the general model. This means that selected parts of the module can be modified, and the general compiler of the whole model will still be able to operate and communicate with the rest of the modules. Such model flexibility allows for a parametrical study of the many variables that must be included in any model. For example, it will allow for an investigation of the impact of the various social networks on energy usage inside a simulated zone/building. The same portion of study examples can be drawn via modification of the other modules.

5 Concussions

This paper is an introduction to the core design of the Building Occupant Transient Agent-Based Model (BOT-ABM). The prescribed format of the paper does not, however, allow for an in-depth introduction of each module functionality, but it is crucial for outlining the most critical features of the model within the overall framework. Therefore, development of such vast human behaviour model requires a multi-disciplinary team and proper feedback from future users. Development of a comprehensive model that capture advance functionalities of building users requires a lot of effort and long-term commitment. Therefore, it is necessary to rely on an existing framework. Presented framework is an effect of the extensive review of existing energy-related occupant behaviour modelling methods. Summarised modelling approaches delivered by Dong et al.[11] and Da et al.[4] allowed to highlight missing pieces in OB modelling and address them. Formulation of this framework can be considered as a result of this investigation which is presented in this paper.

Similar efforts in the formulation of building agent-based model could have been conducted in the past, but there are no records in the available literature. Reasons for such absence is unknown, but it might be suspected that it was caused by problem complexity and lack of proper data. No matter what was the reason, publication of framework proposal will open a new platform to scientific communication and discussion which eventually will lead to the new occupant behaviour model.

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