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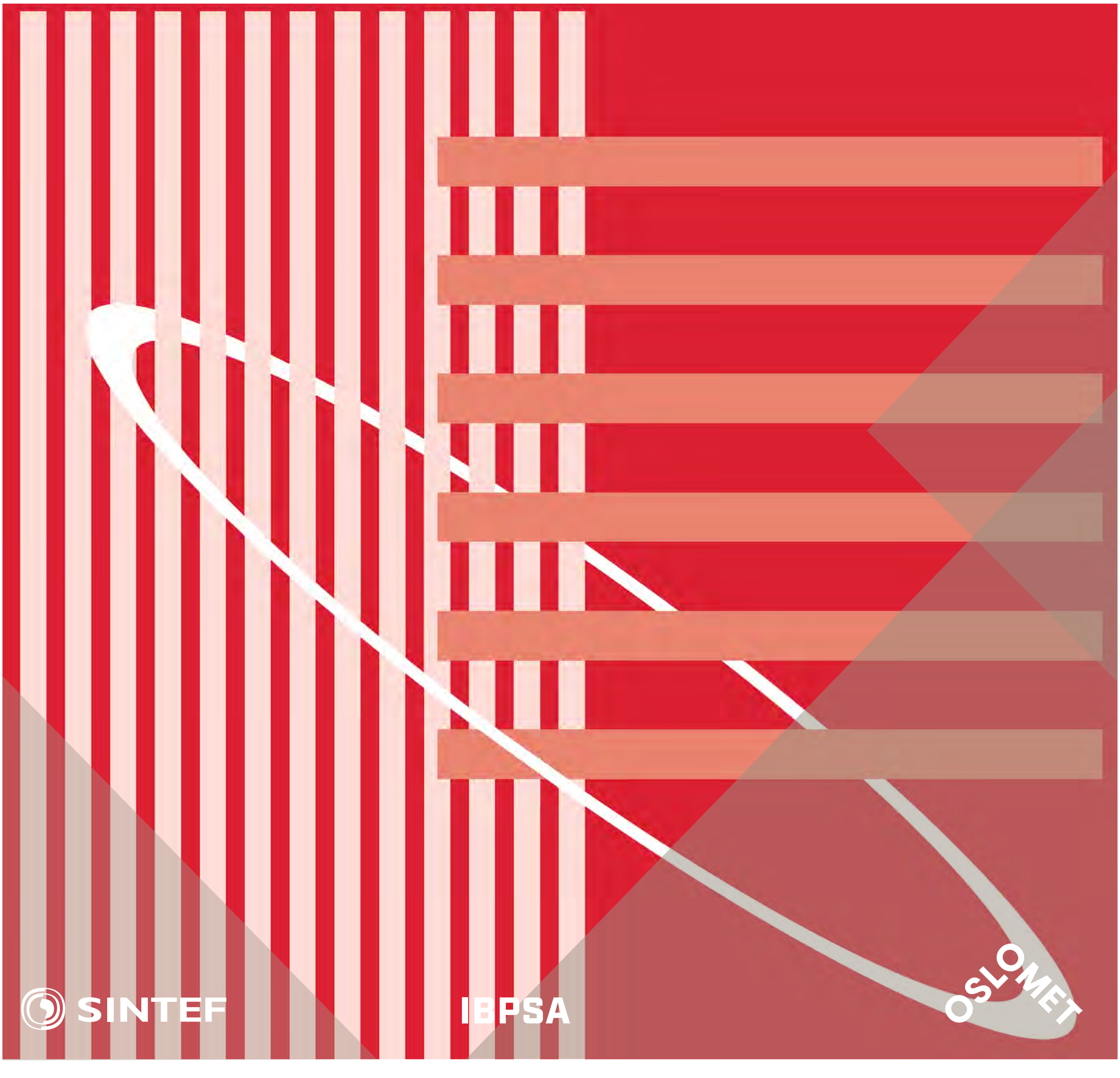

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Editors:
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Exploring possibilities to quantify the qualitative description of occupant behaviour

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Abstract

Human behaviour is a multidisciplinary subject that is being investigated by numerous scientists around the world. The ability to understand and forecast reactions can be beneficial for all scientific branches that are related to this subject. With the increase in the accessibility of personal monitoring systems, a new era of human behaviour research has begun. Currently, in the market, there are many inexpensive and reliable solutions that can grant extra insights into the everyday lives of human beings. Regardless of whether the monitoring solutions are stationary or wearable, they can provide very detailed information with high operational and temporal resolution. Access to these data has advanced our understanding of human routines and habits, but it does not provide insights into the "soft" data that define human beings.

Once the quantitative data has started to enrich scientific databases, the community has started to question whether such information is suitable to detect or record qualitative ("soft") output. Typed text is not included, but it is possible to extract existing data and to obtain "soft" data. This manuscript will try to address this issue. It proposes a straightforward solution that can have great potential for implementation purposes. It investigates the existing literature and tries to evaluate its applicability for numerical implementation. One of the highlights of the manuscript is the proposal of a novel modelling solution that can cooperate with other occupant behaviour-related simulation models. Finally, the manuscript tries to outline future steps to enable the possibility of translating or modelling quantitative input into qualitative output.

Introduction

The possibility of fully re-creating human behaviour can be considered an enormous task if certain boundaries are not stated. The main question depends not only on whether it is even possible but also on the potential simulation goal and the operational resolution. Beyond typically measurable "hard" parameters such as temperature, CO2 or humidity, which can be adopted in any investigation scenario, there is a "soft" side of data, which is considered qualitative information [1]. Such data deliver a subjective opinion about the subject in question. For example, if a person is asked about whether he or she is comfortable, the obtained answer can be hard to quantify. In most cases, the delivered responses might be similar to answers such as "I am fine" or "I feel slightly uncomfortable". The main issue regarding such qualitative output is its measurable repetitiveness [2]. Does such an input operate on a linear scale? If yes, what is the threshold for a specific answer? How similar or overlapping are specific states? If such output cannot be explained based on a linear model, what kind of model should be implemented? These are very important questions, but presently, even with the existence of social media such as Facebook, Twitter and other applications, it is hard to provide a definite answer regarding such "simple" questions [3]. This can be considered a major limitation if the desire is to translate qualitative data into quantitative output. To overcome this issue, the problem could be potentially reversed engineered in a specific way.

It is nearly impossible to ask building users about their satisfaction level during each activity that they are involved in. Even if such measures were possible, the reliability of the results would be questionable. Constantly questioning test subjects about their status would be more like a burden than a support system. After a very short period, participants would become tired or fed up of being involved in such an extensive study, which consequently would corrupt the collected data [4]. Being involved in an experiment would play a major role in their daily routine, and their answers would reflect this phenomenon. To make such interventions more reliable, their frequency cannot go against participants' comfort. Therefore, the sample rate will be rather small, especially if such information is compared with information that can be gathered about the environment. However, this issue does not automatically discredit the applicability of such data. If test subjects agree to be extensively monitored using in situ methods, such quantitative data can be used to formulate an ontology for labelling various activities [5]. Each discrete action observed can be formulated in sequence or parallel scenarios. If the observed phenomena are repetitive, these activities can be labelled as a routine or a habit. During each intervention, an interviewer might present a list of all observed habits and ask about the purpose, feelings and desires that were associated with such activities. In this way, each recorded activity can be labelled, and with the use of sophisticated deep-learning methods, such data can be used to pre-train and to develop a labelling tool. This tool can help to observe and examine quantitative output.

Labelled data would allow to describe the origin of a specific qualitative output. Proposed solution would act as a supportive machine to define whether the specific qualitative output is embedded in psychology, physiology or a mixture of these parameters. If the repetitive pattern of activities constantly provides similar output and for unknown reasons the response is different, then it will be an indication that the origin is embedded somewhere beyond quantitative observation. Therefore, it will enrich the model structure by providing a new branch of connection to the outcomes of actions. Additionally, conducting such a study will highlight the spectrum of activities that could influence human well-being. Such analytics can be conducted at the individual, group or population level, which might highlight the personality differences among test subjects. Studies that try to reach such a sophisticated level of occupant behaviour description have not been found. There might be many reasons for such a situation, but one of the identified constraints might be a low level of interest in the direct monitoring of occupant actions. This situation is changing with each passing year, but the methodology for fully tracking occupant indoor activities has not yet been established. There are studies that focus on this subject such as [6], [7], but studies that track all indoor activities (to a reasonable extent) have not been found in the existing literature.

Since it is currently not possible to translate qualitative data into quantitative information, it might be possible to develop a methodology (application) for receiving a qualitative output from a simulated occupant. For application purposes, it is necessary to establish a framework and to define all potential functionalities that enable the simulation of a “virtual being”. The aim of this manuscript is to define, develop and discuss the possibility of connecting qualitative and quantitative studies about occupant behaviour in residential buildings. The focus is on the possibility of simulating each occupant as a separate “virtual being” and the possibility of obtaining qualitative feedback from them. In this way, the interaction between occupants can be included in the simulation environment. This work is based on a collection of reviewed papers and numerical explorations of modelling practices for re-assembling the typical family. This manuscript has to be considered a hypothetical exploration of the ability to portray the qualitative desires of indoor occupants in a simulated reality. The ability to simulate each particular individual output will open a new dimension with regard to the interaction of virtual occupants. Additionally, this will allow us to formulate a social structure of interactions in which each virtual occupant is an active or passive participant. The motivation among occupants might vary, but it can be considered a main driving force of being involved. For the purpose of explaining each day of the occupants, this is considered a “game”. The fulfilment of a specific motivation is considered a “win”. Each included virtual being will participate in a “game”. For this reason, such a “game” requires a description of its “mechanics”. Studies that focus on simulations of human behaviour can be divided into two main categories: indoor and outdoor simulations.

The occupant is recognized as a crucial part of the building’s “metabolic system”. This is a relatively fresh concept. Therefore, the current time spent on development has allowed the validation of general theories. The use of the metrics proposed by Fanger is considered a good approximation [8]. The proposed approach bounds all building users and defines the principles for the human-centric design of a building’s heating, ventilation and air conditioning (HVAC) system. The solution proposed by Fanger was considered as a state of the art in previous years. It was one of the first attempts to include the “human” factor inside the building. Fanger’s studies could be considered a first milestone that establishes a building’s users as an important factor during the building design phase. Fanger’s discoveries have opened a new methodological branch of building science that focuses on occupant behaviour [9], [10], [11]. Once the subject of interest was introduced, it started to gather a larger audience. It became a foundation for investigating human indoor comfort, and it was extended even further. It has allowed to formulate many highly impactful discoveries about the human indoor environment [12], [13], [14]. Extending the research subject with regard to the impact that an occupant has on a building’s energy systems has allowed us to formulate important theories about energy-related occupant behaviour [15], [16]. Currently, research is part of a larger subject that focuses on building energy performance. The combined efforts of scientists who have contributed to the development of this scientific branch have allowed us to formulate a “know-how” [17] guidebook that tries to describe occupant behaviour investigations in a holistic way. Additionally, it summarizes current knowledge about the subject and highlights new challenges [18].

One of the offshoots of occupant behaviour studies has made it possible to formulate and implement numerous numerical models that are now commonly used in commercial building simulation software, such as IDA-ICE, Energy Plus, DeST or Rhinoceros’ Grasshopper with LadyBug [19]–[22]. Due to the currently available computational processing power, it is possible to introduce more detailed models that focus on individual building users. Currently, there are no guidelines that limit the complexity of the proposed models. As a rule of thumb, the calculation time should allow forecasts of the near future (for model predictive control applications) or annual simulation. Both applications require a different level of temporal and spatial resolution, but in both approaches, the validation process still requires a huge improvement to check its clarity, applicability and robustness. Typically, such applications have a description of the physical properties of the used materials and a simplified energy equation (selection of the numerical methods depends on the software used and application purposes). Additionally, the entire simulation can be enriched with a series of probabilistic models focusing on specific occupant-related aspects such as presence, window and blind operations or plug load use. There are a few more sophisticated methods that try to re-create occupant indoor activities, such as those proposed by T. Hong, in which the occupant behaviour model operates as a functional mock-up obFMU [5].

The simulation of occupants outdoors focuses on the behaviour of the crowd. These simulations are mainly applied to model a specific phenomenon in which the crowd is involved, such as setting up proper sidewalls [23], checking the labelling of streets/large areas [24], setting up a time opening for pedestrian lights or designing escape routes from large spaces/buildings [25]. The description of each particular occupant is dependent on the purpose of the simulation. The description of functionalities is simplified, and a specific simulated feature operating on specific distribution to generate a crowd profile. For example, to simulate a pedestrian crossing light, each simulated occupant must obey the lights to a certain extent. However, the factor of following the rules might be time-dependent. Therefore, if a specific waiting time is prolonged, the threshold for breaking the rules decreases. Combined with an extra occupant following functionality, it is possible to produce a significant model for testing the safety of a street. Both functions can be considered occupant attributes, and levels that trigger specific reaction can be individualized and distributed among pedestrians by certain distribution functions.

Previous studies that have tried to portray occupant behaviour have used a representative occupant [26]–[28]. This means that all groups included indoors or outdoors were represented as artificial occupants that hold the sum of all actions. In those cases, there is no individual simulation of behaviour, and all actions are captured in a group-size resolution. The model data obtained in such a manner can be used as a support for future development attempts, but precise information on individual actions plateaus. The data used for these observations were collected mainly from interactions with various controllers (such as a thermostat [16]) and indoor monitoring devices (such as plug load metres or the PIR sensor [16]). Even without high spatial and temporal resolution, it is possible to distinguish a few types of representative energy user archetypes [29], where their behaviour operates on two dimensions related to energy awareness and general wealth. Despite the lack of individualization, such studies can be used to develop a database of all potential activities. It has to be pointed out that such an approach guarantees the stability and direct reproducibility of the study due to the operation on a purely statistical basis. This flattens the specific context (knowledge of users) but delivers a model that is reliable. This model representation of users offers a probabilistic approach, which is sufficient to a certain extent. If an investigation target focuses on personalized control, it is necessary to implement solutions that involve a more deterministic approach. It is very common to justify and explain occupant behaviour with the use of stochastic methods. Although they are a convenient method for describing repetitive actions, where the initializations might vary due to numerous implications, stochastic methods are a simplification of deeper phenomena [30], [31]. The use of this methodology implies that occupant behaviour is a stochastic process, which contradicts its deterministic nature. Put simply, the actions of occupants depend on proper circumstances and motivations, not a randomized action. Therefore, to create an individualized simulation for a specific building user, it is necessary to operate on a similar structure. The closest method that operates on similar principles is a pre-trained artificial intelligence model.

The urge to define occupants as individual "virtual beings" in a simulated environment is also suggested by other scientific branches, such as medicine [32], and sociology [33], [34]. However, these branches can also be connected by topics focusing on energy usage by various social groups. Most of these studies aim to recognize the current understanding of energy uses inside residential houses from the perspective of their own scientific context [38]–[42]. One investigation subject that can be explored is the impact of ICT on the structure of the family or how occupants understand the concept of energy savings. This study allows for a multidimensional analysis that can be related to sociology, psychology and energy studies. Unfortunately, such studies are carried out in a relatively small group of participants, but they still provide valid and representative output. The utilization of the insights gained allows the construction of a model that relies on a typology of activities, similar to Pavlovian conditioning [40]. Such an application can be a separate model, or if its structure has a modular application, it can be considered a module of a larger occupant behaviour simulator [41].

Aim

From the qualitative research perspective, there are a few models that can be implemented in functional applications, such as the theory of planned behaviour or Maslow's hierarchy of needs [42], [43]. The main issue regarding these modelling approaches is their Eulerian nature. This means that the proposed models have a clear and understandable structure, but their implementation is difficult. For this reason, it is necessary to try to approach this issue with a more Lagrangian approach, where the structure of the model might be more complex and convoluted, but implementation will be more straightforward. The main aim of this manuscript is to define and describe the process of developing an occupant behaviour model/module that delivers qualitative data as an output. Due to the lack of data that can completely support this process, the whole development will rely on existing studies, discussions and conclusions provided by the literature. Additionally, the whole model/structure is designed from the implementation perspective.

Studies in the literature have shown that there are a few examples of attempts to approach the qualitative output issue. Unfortunately, deeper analysis does unravel the problem is relatively ignored [15]. In this study, the attributes of particular occupants are defined as a trigger to carry out an action, which is counted as the fulfilment of a need/desire. This could be considered a "shallow" ontological approach in which specific needs can be met by a selected driver, which, to a certain extent, is correct, but its structure limits the existence of other options. In other words, models are blocked by this framework.

To address all these issues this manuscript will try to develop a semi-open structure for a framework in which each sub-part of the model is described. To not overextend the subject, the proposed simulated model will be tested to simulate two specific scenarios that were investigated in previous studies.

Methods

First, with regard to the description of model development, it is necessary to define all the vocabulary used and the basic mechanics of the "game". This manuscript is operating on the edge of engineering and sociological studies, and each of these fields has similar terms, but their meaning might vary. Therefore, it is necessary to define an operational library. Each simulated person is considered to be an occupant. Each occupant is simulated individually. The qualitative model output is considered a defined spectrum of answers from simulated occupants that informs the status of goal fulfilment. There is no predefined pathway that will promote fulfilling a goal. The goals are defined as a target of actions or a state that one specific occupant has to obtain to fulfil his or her personal needs. Personal needs are the pre-defined boundaries of each person that cover a spectrum of basic human needs, such as hunger, stamina, and social interaction. Each target has its selected description that defines the conditions for reaching it, what is an acceptable buffer and what is a qualitative outcome. For the purpose of theoretical analysis, this study will limit itself to five specific needs (Entertainment, Hunger, Hygiene, Social interaction, Stamina), which are usually mentioned in research related to the description of personality [44]–[46]. The "game" is a simulated activity with a selected time horizon. A whole "game" has four main layers, and the first layer defines the rules for reaching the target. The second layer focuses on relationships and the relations of the simulated occupants. The third layer focuses on describing the elements of the activities and actions that the occupants have to take to be involved. This layer can be considered a building block for formulating the action. The fourth and final layer describes the occupants individually. The result of each game is ultimately connected to two outcomes, winning or losing. A "win" is an outcome in which the target desire is fulfilled while staying within the boundaries of personal needs. Losing is considered a state where one or none of the winning elements is not fulfilled. The outcome of the "game" influences the qualitative state of the simulated occupant. Winning boosts the level of well-being, and losing decreases it. Well-being is a one-dimensional variable that operates on a mathematical plane of real numbers. If the value is positive, the occupant reports a positive state, and vice versa for a negative value of well-being. It is a time-dependent variable that aims to obtain a neutral zero value. This process will be called "mood neutralization". The dynamics of this parameter can vary between occupants, but for this approximation, the parameter will be held constant at a selected value. Therefore, each occupant has one linear curve of mood neutralization. To make the description more transparent, each layer of this model will be described in descending order in a separate subsection.

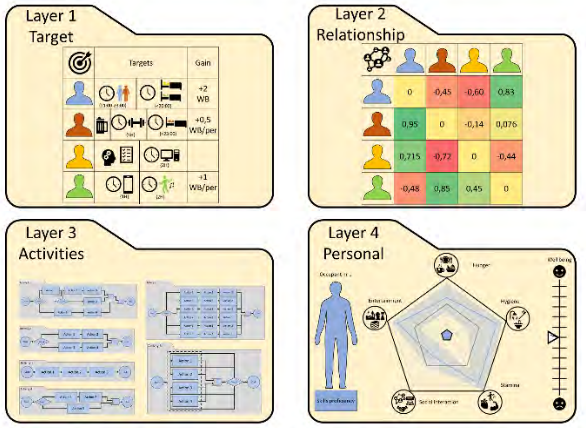
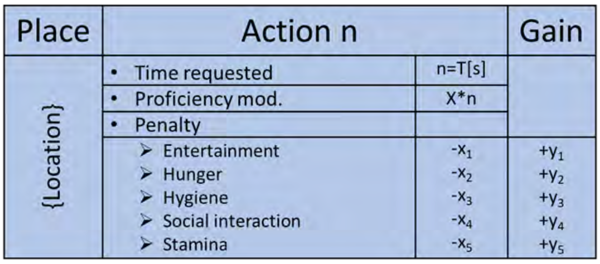


Figure 1. Layer structure of the whole model

The structure of each target is the same in terms of the framework, but the selected conditions have to be defined on an individual level. Such an implementation allows us to formulate means of personalities and allows space for the potential simulation of the personal evolution of the needs of occupants. The qualitative outcome of a simulated activity strictly depends on a buffer of acceptance, which makes acceptance a dynamic variable. If a simulated occupant "wins" the "game" even without being fully in aligned with his or her personal needs but is still inside the buffer zone, the occupant's personal needs will be impacted. If such an event occurs more frequently, the description of personal needs will evolve. It is possible to forecast that if such a numerical simulation is left alone (continuous simulations of daily activity), it will tend to generate "pathological" scenarios where one participant will be overused. This will consequently lead to a reinforced shift in personal needs. Such a situation might happen in real-life scenarios, but in most cases, it will not happen in a short period of time. To counter the development of an excessively accelerated change in personal needs, it is necessary to implement a negative reinforcement. This will gradually reduce the previously gained modifications of the personal need parameters. In terms of the core structure, in whole "games", there are three times more losing than winning outcomes. Therefore, observing the "personal" evolution during the simulation process must be connected to a constant positive "game" outcome. To implement this functionality, each occupant has to hold a memory of the baseline of each personal need and the changes that occur due to modifications. To make the description more transparent, the whole model structure is presented in Figure 1.

Reaching the target requires performing all the actions in a series of activities. All of the actions are operating on a global time step. Each activity that can be performed in the real life is considered as a series of actions that are defined by the specific activity. The completion of one action depends on the time and effort spent on performing it. It is a cumulative threshold value that triggers a confirmation that the action has been completed. There is no qualitative evaluation of the action performed. If there is an action that does not require constant involvement, in its description, there is an additional "NaN" parameter. This means that the action has at least three threshold cumulative values, where the first defines the amount of time that has to be spent to reach the "NaN" status. The second threshold defines the amount of the cumulative time value until the action will stay inside the "NaN" status. During this time, occupants cannot accelerate the process by using their skills. The third threshold defines the amount of the cumulative value that is necessary to finalize the activity. One activity can have more than one "NaN" status, and its appearance depends on the types of actions that are defined. It is assumed that occupants are aware of the structure of whole actions. During the "NaN" status, occupants gain an additional timeline that can be used to perform any other action. For example, to boil water with the use of an electric kettle, it is not necessary to wait for the entire boiling process. This time can be used to become involved in other actions, which are defined by the activity. Each time step that contributes to the completion of actions reduces the amount of stamina of occupants. From the operational perspective, actions are defined by two variables: time-dependency and score-ability. If an action is time-dependent, this means that its appearance exists during the specific moment in the timeline. If the targeted occupant will not engage in performing the action within a defined time window, this action is concluded and cannot be performed. Scoreable actions are events in which the performance of such actions has a direct influence on the whole activity. Therefore, the outcome has an influence on the entire activity that the occupant was involved in. To summarize, activities can be divided into four groups separated by two variables, (time-depended scoreable; non time-depended scoreable; time-depended non-scoreable; non time-depended and non-scoreable). The visualization of the action block that can be used to model the whole activity process is presented in Figure 2.



Place	Action n		Gain
{Location}	• Time requested	n=T[s]	
	• Proficiency mod.	X*n	
	• Penalty		
	➢ Entertainment	$-x_1$	$+y_1$
	➢ Hunger	$-x_2$	$+y_2$
	➢ Hygiene	$-x_3$	$+y_3$
	➢ Social interaction	$-x_4$	$+y_4$
	➢ Stamina	$-x_5$	$+y_5$

Figure 2. Action module structure with all necessary inputs and outputs

The completion of a specific activity depends on two functions, proficiency and focus. Proficiency is a fixed function that describes the experience of the occupant in performing a selected action. The more similar the category of actions performed, the more skilled the occupant becomes. The proficiency level accelerates the process of performing an activity. It can be considered a multiplier for its completion since actions are performed based on an accumulation of time steps that occupants use to participate in these actions. The action proficiency level will multiply the value of each time step that was used for these actions. The focus parameter is a survival model that defines the amount of time that a specific occupant will stay focused on an action. The survival model is a probabilistic time function that describes the amount of time that specific phenomena will last. It makes it possible to describe one-dimensional phenomena in which the chances of occurrence increase over time. For example, with this approach, it is possible to simulate the time until a window will be shut once it is opened. Initially, the chances that the window will be closed are small, but once time starts to pass, there are higher chances that it will be closed. This approach is usually supported by a prolonged period of observations. Observed phenomena are investigated based on the time they last, and aggregated data allow us to formulate a distribution. The formulated distribution becomes the foundation of the survival model. This model will be implemented to simulate the focus of the occupant and to provide the solver that will be responsible for simulating the attention time spent. The shape of the curve is dependent on numerous variables, and due to its simplicity, it is possible to introduce its modulators. Some impactful parameters might be age, the time of day, weather conditions, the amount of stamina or open timelines due to the parallel involvement in a few actions.

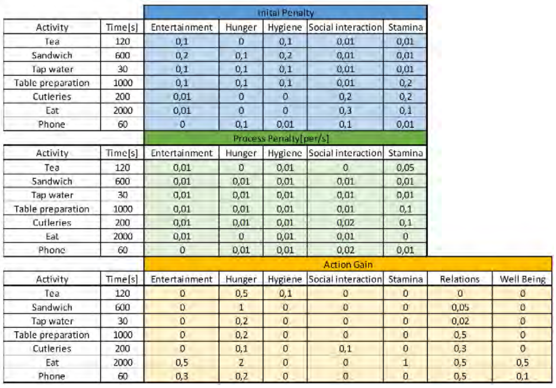
The simulation of the whole activity requires a precise definition of its sub-elements (actions). The whole sequence of actions has to be defined, with its characteristics, the cumulative time required to complete it, the necessary previous actions and the amount of necessary resources to finish it. The global order within one activity does not have to be fully specified. Some actions have to be followed by other actions, but some can be carried out in parallel. Additionally, an activity has to define the maximum number of occupants who can conduct the activity. The use of this structure allows the formulation of various scenarios. This requires defining each activity separately, but this allows us to formulate various, more realistic scenarios. The logic of the actions is not directly defined. Therefore, it is possible in such a structure to define unreasonable activities and to observe their impact. The larger the database of defined activities is, the more sophisticated simulations can be conducted. If an activity is completed, it grants specific rewards that are defined by the activity description. An activity can be built from at least one or more actions. With such a structure, it is possible to introduce the utilization of resources. This could be an additional trigger for a new spectrum of activities that rely on the control of resources levels. For the current form of the model, such a feature will be avoided because it would demand a significant effort to define the operational library. For the current state of the model, it is assumed that occupants have access to all the resources necessary to perform each activity.

The relationship layer defines the hierarchical structure of the group. It has a significant impact on the whole model. The time spent on each action can be modified by the number of people who can be involved and the number of people who will be impacted. For example, the time necessary to prepare a meal for one person will be different from that preparation of a meal for a whole family. Additionally, the potential involvement in collaborative efforts can affect the process of completing activities. If there is a difference in the proficiency level among the occupants who are involved in an activity, the occupant with the highest proficiency level will become the supervisor of the task. The supervisor will have a reduced amount of focus on the task because he or she will be controlling the others, but the proficiency level of the supervised occupants will grow faster. The proficiency level can grow to the level of supervisor. These are the rules of the task-based hierarchy that allow us to define the main person responsible for an activity that is being performed. It is assumed that the proficiency parameters are known to each occupant, as well as all other personal need parameters. Each time a task is performed by more than one occupant, the social interaction need parameter of each occupant increases. If an occupant's action involves only one person, the same parameter is reduced. Beyond the local hierarchical system, it is necessary to establish the global hierarchical system among the occupants included in a simulation. This feature will influence the involvement in actions, where a spectrum of activities must be distributed among occupants. If this parameter is left unsupervised, it can produce an uncontrollable artefact. The global hierarchical system is established in the relationship matrix, and it is assumed that the main decision makers are the parents. Therefore, if the list of activities must be distributed among the occupants, occupants representing parents will define who is involved in a specific task. In this structure, it is possible to implement a sub-layer that represents a negotiation phase, where a child can try to disobey parent and where the combination of basic-need parameters might play a significant role. For the development of the current model, this functionality will not be introduced.

Reaching the target of the "game" requires completing specific subtasks that are dictated by the ongoing daily routines. Each occupant has his or her own targets that he or she is motivated to achieve. Reaching a target requires completing a series of activities. If a target is reached with a successful score, it boosts the well-being variable. The status of well-being can change during the occurrences of various events. The current structure of the "game" assumes that each occupant aims to "win" his or her "game". The main idea of the "game" is to constantly involve the occupants in "play". Their statuses over time will be modified by the actions in which they will be involved, which can be used to evaluate their qualitative response in any selected time step. The initial conditions will play a significant role, especially if there are implications connected with having a low status of well-being variable. The current status of the whole model must be considered an initial approach for building a sophisticated occupant behaviour simulator. The methodology section describes many interactions between the different layers of this model. The interactions vaguely define the components and mechanics behind the model. Access to data that would define more concrete, quantitative connections is currently not available. For this reason, it is necessary to fine tune all the parameters to make a model functional; this will be the focus of the analysis (results) section.

Simulation setup and results

To set up simulations, it is necessary to define a set of specific actions and activities and the target of each occupant. This manuscript will test the scenario of evening routines. The whole set of activities and the necessary actions are displayed in the process graph, in Figure 3. The idea of the simulation scenario is adopted from a study on the influence of ICT on a one daily routine (Activity), family dinner. [36], [47], [48]. In the simulated test case, a family consisting of four members, two parents and two children, was generated.



		Inital Penalty				
Activity	Time[s]	Entertainment	Hunger	Hygiene	Social interaction	Stamina
Tea	120	0,1	0	0,1	0,01	0,01
Sandwich	600	0,2	0,1	0,2	0,01	0,01
Tap water	30	0,1	0,1	0,1	0,01	0,01
Table preparation	1000	0,1	0,1	0,1	0,01	0,2
Cutleries	200	0,01	0	0	0,2	0,2
Eat	2000	0,01	0	0	0,3	0,1
Phone	60	0	0,1	0,01	0,1	0,01

		Process Penalty[per/s]				
Activity	Time[s]	Entertainment	Hunger	Hygiene	Social interaction	Stamina
Tea	120	0,01	0	0,01	0	0,05
Sandwich	600	0,01	0,01	0,01	0,01	0,01
Tap water	30	0,01	0,01	0,01	0,01	0,01
Table preparation	1000	0,01	0,01	0,01	0,01	0,1
Cutleries	200	0,01	0,01	0,01	0,02	0,1
Eat	2000	0,01	0	0,01	0,01	0
Phone	60	0	0,01	0,01	0,02	0,01

		Action Gain						
Activity	Time[s]	Entertainment	Hunger	Hygiene	Social interaction	Stamina	Relations	Well Being
Tea	120	0	0,5	0,1	0	0	0	0
Sandwich	600	0	1	0	0	0	0,05	0
Tap water	30	0	0,2	0	0	0	0,02	0
Table preparation	1000	0	0,2	0	0	0	0,5	0
Cutleries	200	0	0,1	0	0,1	0	0,3	0
Eat	2000	0,5	2	0	0	1	0,5	0,5
Phone	60	0,3	0,2	0	0	0	0,5	0,1

Figure 3. Sample action table with variables necessary for simulation

Setting up this simulation requires performing a series of sensibility analyses to establish the accuracy rates and parameter modifications to reach a balanced output. The analysis of the parameter weights is shown in Figure 4. Setting up the first simulation requires a certain stabilization of the parameters to control the tuning procedure. For this reason, it is assumed that everyone is involved in activities and that occupants have the same initial personal parameters.

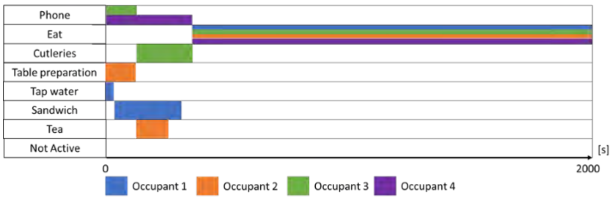


Figure 4. Simulated action sequence results

Each occupant performs his or her action and is a part of the activity process. Their actions do not operate on any dimensions other than time, at least for this approximation of the model. The lack of a physical connection makes it possible to operate on an abstract plane of the whole process, where involvement in a specific action can be visualized. Each occupant has his or her own "game", which can be considered a process. Each occupant has its own needs that are evolving thru the actions that are involved. The results of this simulation of occupants' needs are displayed in Figure 5.

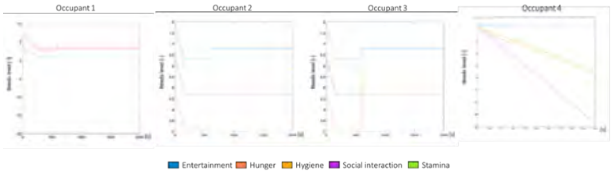


Figure 5. Occupants' needs simulation results.

Discussion

The ability to simulate occupants' qualitative output is a novelty in the research field. Performing validations of this concept would require conducting multiple tests, where trained personnel would collect data for this purpose. It is a challenging task, but with the selection of a specific mechanics, it is possible to narrow down the number observations necessary to complete such a task. Put simply, once the framework is established, it is easier to define the goals of observation.

The proposed model is developed with an application goal. It is recognized that occupant well-being has a significant impact on the performance of occupants, and this parameter must be included. The main issue with "soft" parameters that describe occupants is the lack of knowledge about how to include them in a simulation. The issue is exacerbated if it is assumed that feeling and sensation are a subjective, personal experience. If such a status is accepted, the development of this model has to be defined by each separate person. This would require a detailed "bottom-up" approach, but certainly, it is possible to implement this methodology in small test cases.

The proposed model is built from the engineering perspective, where actions are followed by the reactions of the overall model. Studies that followed a similar procedure or that investigated human behaviour in similar matter were not found. There are many good models proposed in a past, that define human drivers and that describe human dynamics, but none of these descriptions allow us to atomize the content of the investigation. This means that tremendous efforts that were made to develop a structural model do not allow to extract the contents of actions and reactions. Existing studies can be considered inspirational, but the qualitative data that they collected are far from being considered for implementation in numerical simulation. Additionally, current control of status parameters requires more tuning, but this should be fixed once the proper measurements are conducted.

The main disadvantage of the proposed model is its reliance on action, activity and human profile libraries. This requires access to a huge variety of activities to function correctly. Development of vast library is beyond one research group or project. To develop such a database, it is necessary to involve volunteers. With the formulation of a proper survey, participants can be asked to describe their daily routines. Each routine can build from action/activity blocks. These blocks will represent each action that occupants can be involved in. While describing an activity, participants can be asked about the benefits and requirements that are related to routine, activity or action. In this way, it would be possible to develop a crowd-sourced database that defines daily activities. Each similar routine could have multiple, different actions included, or its order may vary. Once the data base is saturated with a significant number of activities, it can be implemented in the proposed model.

The complexity and variety of scenarios can be extended nearly to infinite. Especially if each included in simulation occupant has an extensive list of factors that might influence the motivation and need. Even if the amount of the influential parameters would be limited to a small number, the core design of the proposed numerical solution promotes lack of direct reproducibility, but the reasoning of the actions is capped. Each action can be stopped or initialized based on specific, defined distribution. Each distribution function can be modified or transformed by numerous conditions like weather, health, type of event, date, relationship to other occupants or others. Combination of all of these factors influences occupants engagement in action. If all of these parameters are also time depended, the level of complexity rises exponentially. This is a significant limitation because it does not allow to validate the proposed model on an operational level. The proposed solution can be tested with the use of the stochastic methods, which will blur the main context of the model. It will not draw one single cue of actions, rather a set of cues that are emerging into a similar status. If the rules of the proposed "game" for increasing well-being status are considered as a correct, the direct link between the motivation of actions and reaching the goal can be measured by means of entropy. It changes the mathematical apparatus and do not discards the story that leads to effect. It instead evaluates each action, or piece of a timeline how it declines from the goal.

Additionally, it is important to discuss the pros and cons between simulation and rule-based modelling. Both approaches are fundamental, but each of them has its flaws. Numerical simulation operates on a non-natural random number generator. If such setup is left running without any supervision (rule), it will not produce any consistent results. Each simulation has to have its limitations that are stated by the set of rules, for example, the level of convergence or boundary conditions. On the other hand, fully rule-based methods will not promote any diversity; the rules are followed until the fulfilment conditions are met. Incorporating occupants simulation by the use of these methods as a seldom solver is inapplicable. It is possible to assume that each person has its plan (cue) of action set in a logical order. However, such a plan could be considered as rational only for them, due to their limitations or personal triads. Therefore, the fully rule-based methodology cannot be applied. Promotion of any diversity among the simulated individuals, requires introduction a certain amount of variety, that can be found in simulation methods. To somehow overcome issue connected with both of these methods, it is necessary to combine positive sides of each approach and overcome existing disadvantages. Such a task is an important limitation because it requires a definition of how rule-based or chaotic is a specific person and their personality.

The development of this model aims to be implemented in a building performance simulator. There are existing building numerical models that could potentially operate on outputs provided by this model [41]. For this purpose, access to an activity scheduler would be a significant asset and would allow to simulate the realistic utilization of energy resources. Currently, the available functional models do not allow us to track the reasoning of individuals. The links of cause and effect are broken by implementing fixed schedule or time-series models [49]–[51]. In proposed model, it would be possible to trigger interaction with a simulated building infrastructure. Therefore, each action would have its own marker. Similar to the block-chain technique, each component of the simulation would hold a permanent record of who was using it and when. Incorporating the well-being status would introduce a new dimension that could influence the energy usage of the building. In particular, the link between occupant thermal comfort and well-being could be established.

Conclusion

The idea presented in this manuscript tries to capture and implement in simulation software artificial qualitative responses of human beings. The main aim is to implement a systematic solution that can be further developed. Due to the limited resources applied, this methodology cannot be extended, but its current state can be used as a reference framework. It is difficult to judge whether such a methodology is fully correct from the social science perspective because the work presented is a mock-up. Its main advantage is the possibility of simulating the human-interaction process, where each included person plays his or her role in reaching his or her goals. The proposed solution has a relatively simple core structure, but the interconnection between parameters starts to increase the level of complexity significantly. The design of the model and its key parameters was selected to be fully used during simulations. This indicates that such similar parameters should be considered when performing a model validation data collection procedure.

Based on existing studies, it is possible to extract pieces of information about how the model delivers qualitative output. The closest approximation can be found not in the scientific literature but in interactive entertainment systems. Pieces of software that focus on a procedural world building environment develop similar simplified tools, but their applicability is questionable. Applications such as Dwarf Fortress or RimWorld focus on a computer simulation of societies where each new application user delivers a unique social network and history of events and relations is shared between non-player characters (NPCs) [52], [53]. It is obvious that it is impossible to program all of the connections between NPCs; therefore, an algorithm that is dedicated to such a task must exist. Additionally, substantial access to the computer's rapid access memory must be held to operate with all of the connections that are delivered during the simulation process. It is expected that the only applicable solution for handling social interaction and simulating qualitative responses can be achieved with the use of procedural techniques. Procedural generated interaction is relatively simple in a core design, but it allows to build advanced scenarios without the extensive influence in software code.

The initial challenge that was presented in this manuscript concerned questioning the possibility of translating qualitative human input into accurate quantitative response output. Such a task can be considered unachievable due to the overcomplexity of human nature. However, the combination of extensive in situ monitoring techniques and the further development of the proposed model can be a solution to this task. It requires appropriate detection ontology, recognition of an observed person, and detection activity that the observed person is performing. Those parameters can be an initial input to pre-training the model that is presented in manuscript. Once the significant training is completed, the monitored occupant can be evaluated in terms of his/hers potential qualitative output. Such a combined system can be considered a model predictive control for human qualitative response (MPC-HQR). The use of such a technique is blocked not by the current limits of technology but by the critical mass of activity descriptions and number of studies that share similar methodology and framework. Once this status will be changed, collected data can be process with a support of advanced statistical methodologies. The contemporary advancement of machine learning and deep learning techniques makes it possible to precisely classify data without a significant amount of computational time. Usage of this technique with collected information would allow to train a labelling tool for proper qualitative recognition. With this knowledge, it is possible to conclude that once a proper targeted study that aims to collect different activity scenarios is conducted, it will be possible to reach application of MPC-HQR in a relatively short period of time.

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