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Abstract: Simulation of occupant behaviour (OB) in buildings is a challenging task. Available software uses a broad spectrum of tools that try to reproduce the patterns of human activity. From building energy perspective, the main emphasis in research has been focused on discovering behaviour directly related to energy. In recent years, more attention has been given to simulating occupant actions that are indirectly influencing building energy use. In most of the cases, this is achieved with the use of agent-based modelling. which allows describing occupant actions on a room level. According to the existing methodologies review, it is a proper step, but to include occupant behaviour in energy simulations, spatial and temporal resolution of the occupant behaviour model must be improved. Addressing this issue requires the development of a comprehensive model supported by numerous modules that would cover various significant occupant actions. This paper focuses on the development of the high-resolution, data-driven movement engine of occupants. It is one of the fundamental modules necessary to simulate occupant behaviour with high granularity. Once the model is developed within its essential functionalities, it will deliver a bottom-up model capable of testing various energy use strategies. It will allow for testing different heat, ventilation and air conditioning solutions and the responses provided by simulated occupants. The data used to develop this module was obtained thru in-situ measurements, with the use of depth registration. Information obtained from experiments is similar to previous research, but it also extends the investigation scope with an additional transition-based variable.

***Author Contributions Section**

Jakub Wladyslaw Dziedzic: Conceptualization, Methodology, Software, Investigation, Writing - Original Draft, Visualization, Validation , Writing - Review & Editing

Da Yan: Methodology, Formal analysis, Writing - Review & Editing

Hongsan Sun: Methodology, Formal analysis, Validation

Vojislav Novakovic: Formal analysis, Writing - Original Draft, Supervision, Writing - Review & Editing

***Declaration of Interest Statement**

AUTHOR DECLARATION

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We further confirm that any aspect of the work covered in this manuscript that has involved either experimental animals or human patients has been conducted with the ethical approval of all relevant bodies and that such approvals are acknowledged within the manuscript.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs. We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from (jakub.w.dziedzic@ntnu.no)

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Reviewer #3

1. Qestion1 Still, some minor grammar mistakes need to be fixed, especially for the newly added part, e.g. section 4.

Answer: Dear Reviewer, thank you for pointing it out. We have checked whole manuscript and addressed grammar and language issues. Addtionaly, we have slightly re-organized text to make it more clear.

2. For the final paragraph of Introduction Section, the authors fixed the statement of "there are no ABM focusing on building occupant behaviors", but later they mentioned "With these parameters, it is possible to simulate complex fire escape scenarios with various placements of the fire origin…". It seems that most of the descriptions are from one reference that is related to fire escape, while ref [26-34] mentioned many other application areas. The authors should either point out which research they are referring to when talking about fire escape, or make the part read more coherent.

Answer: Dear Reviewer, thank you very much for pointing it out. We have slightly change the sentence to make the text more coherent. Also, we have noticed that enlisting the different agent-based models in the previous sentence was not in corresponding order of reference. Therefore, to make it more readable, we edited this part as well.

3. Section 3.6, it should be "Figure 5" in the text, instead of figure 4, since the authors added one figure in the new version. Such mistakes should all be avoided (similar errors in section 5, among others).

Answer: Dear Reviewer, thank you for highlighting this issue. We have rechecked the whole manuscript and addressed the issue in all apperiances where figures were miss-referenced.

4. For section 4, second paragraph, the authors explained that, if the agent fails to transit into the target in 10 times average steps needed, the transition is considered as outside layout. But should it be "too many steps" in this case? Otherwise, how do you define "too many steps"?

Answer: Dear Reviewer, thank you for pointing it out. It should be “too many steps”. The part was edited as yousuggested

5. Minor mistake in section 4: "This will include all functionalities besides EED", "besides" should be "except".

Answer: Dear Reviewer, thank you for pointing it out. Now it is corrected according to your suggestion.

6. For section 5: Result, it is more of a simulation testing/case study of the proposed method. Maybe it could merge with section 4, or more appropriate section title can be used. This is only a suggestion, while not a critical issue.

Answer: Dear Reviewer, it is a valid point, but merging might cause more confusion among the readers. Therefore, we re-named the results section to "Simulator sample results."

Editors:

Comments by editors were not well addressed in details. Many issues raised in comments were not addressed.

Answer: Dear Editor, we secerely apologize four misinterpretation of your message, this situation should not happened.. In this resubmission, we tryed our best to increase the quality of the manuscript, by addressing all your comments. All the your comments in this and the first reviewing round were taken into consideration. All the modifications were addressed step by step. Hopefully, all the added or modified content will make this manuscript more transparent and easier to follow.

1. For example, lump sum reference citations in the main text still exist.

Answer: We have checked our first revised version without marked changes, and we cannot find any lump reference citations. But maybe there was an issue with automatic reference format. Therefore, we have broken all automatic links and add references manually.

2. Literature review were not updated throughout and orgaqniszation and language still need to be improved etc.

Answer: Dear Editor, we have tried to update the literature to the most relevant and recent studies related to the subject. First submitted versions had 14 fewer references, and as reviewers suggested in the previous reviewing round, we added extra relevant literature. Of course, there is a possibility to add extra references because agent based-modelling is a rich and vast subject. As far as we understand, the original research paper reference should be used to build the case and highlight the novelty of the proposed research. That is why we selected the references that are fulfilling this purpose. Regarding the organization and language, indeed our work could be improved. Therefore, we have implemented changes in selected places.

3. Please revisit the comments again and address them in the format of point by point.
   3.1. The relevance to Applied Energy should be enhanced with the considerations of scope and readership of the Journal.

Answer: Dear Editor, this issue was addressed in a previous review. Abstract and Introduction section were changed, respectively.

   3.2. A proof reading by a native English speaker should be conducted to improve both language and organization quality.

Answer: Dear Editor, a certificate of proofreading by a native English speaker was added to the cover letter. After all the corrections, our paper was checked once again by the native-speaker.

   3.3. Please avoid using abbreviations in the TITLE, HIGHLIGHTS, ABSTRACT and CONCLUSION if possible.

Answer: Dear Editor, thank you for this comment. There were no abbreviations in the title and highlights section but there were few in abstract and conclusion section. We did the correction according to the request.

   3.4. Please also avoid "lump sum references", such as XXXXX [1-5]; all references should be cited with detailed and specific description. In the references, all authors should be included, avoiding using "et. al.";

Answer: Dear Editor, all these issues were addressed in a previous revision. Now there are no “lump sum references.”

   3.5. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point).

Answer: Dear Editor, such file was formulated from the beginning of our manuscript submission and Highlights bullet points are fulfilling the restriction. In the first submission there ware minor issues related to this section, but it was addressed on the first revision.

   3.6. TITLE: It normally consists of about 12-15 keywords which shall not be too general or too narrow.

Answer: Dear Editor, we want our title to reflect that proposed simulator is a part of the bigger occupant behaviour model. The subject pin-points that this manuscript main focuse is given to the movement simulation. It shows what is the main point for this paper and what is the main scope

3.7. HIGHLIGHTS: Highlights are mandatory for this journal. They consist of a short collection of bullet points that convey the core findings of the article and should be submitted in a separate editable file in the online submission system. Please use 'Highlights' in the file name and include 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point).

Answer: Dear Editor, as similar in comment 3.5, we compose the Highlights according to the guidelines provided in the main page of the journal.

3.8. ABSTRACT: It should be about 150-250 words with concise text in a single paragraph. Answer the questions: What problem did you study and why is it important? What methods did you use? What were your main results? And what conclusions can you draw from your results? Please make your abstract with more specific and quantitative results while it suits broader audiences. Abstract stands alone, no references, figures, tables or equations are cited.

Answer: Dear Editor, your comments from the first review were pointing out this issue. We have substantially modified the abstract to make it more accurate and infromative with a respect to jounral limitations.

3.9. CAPTIONS: Captions for figures and tables should be presented with more specific description rather than a general sentence like "Results of the experiments ...", "A studied system ...."

Answer: Dear Editor, each figure is captioned with a precise matter, all the insides necessary to understand the figures are provided in captions.

3.10. UNITS: SI units shall be used.

Answer: Dear Editor, all the data are presented in SI units.

3.11. DATA: All data shall be carefully presented with consistent accuracy.

Answer: Dear Editor, all the data presented in the paper, are presented by the graphs with special care to the details. Addtionaly, all the used data operates on a same accuracy, wich solve consistency issue.

3.12. The originality of the paper needs to be further clarified. It is of importance to have sufficient results to justify the novelty of a high quality journal paper.

Answer: Dear Editor,this issue was addressed in the previous review round. A similar comment was delivered by the first reviewer, and our efforts lead to significant improvement of the abstract, introduction, and methodology section. The aim, novelty and foundings are highlighted in the submitted manuscript. We believe that proposed methodology will be implemented in a new version of building performance simulation software, due to its simplicity and robustness. Our believe in the proposed simulator is expressed in the conclusion section.

3.13. An updated and complete literature review should be conducted to present the state-of-the-art and knowledge gaps of the research with strong relevance to the topic of the paper.

Answer: Dear Editor, this issue was already addressed and commented in your comment nr 2. We have tried to pin-point the current state of the art in building performance simulation and occupant behaviour simulatiors

3.14. -The results should be further elaborated to show how they could be used for the real applications. Modeling results should be validated by experiments.

Answer: Dear Editor, this issue was addressed in the previous round of review. The usability of real applications are enlisted, and the model was validated.

Cover Letter

To the Editorial Board of the Applied Energy Journal

We would like to re-submit our paper “BUILDING OCCUPANT TRANSIENT AGENT-BASED MODEL - Movement Module” to your journal as an original article. As we mentioned previously, presented work in this paper explores the usage of the motion capture technique for observation of the building occupant behaviour. Collected data via this method allowed formulating the occupant movement agent-based model inside buildings. The generated model operates in a detailed temporal and spatial resolution. The level of the model accuracy allows for simulation of complex behaviour scenarios inside the building while keeping a simple construction of the solver. Ability to re-create the occupant's actions inside buildings allows for depth analysis of their energy-related behaviours. Therefore, it is possible to investigate the impact of particular building design decisions on building total energy use.

Investigations of the occupant behaviour in buildings is a broad scientific subject that involves multidisciplinary group of expert. Therefore, such paper will be appealing to the scientific audience related to the building science like architects, civil engineers and mechanical engineers. Additionally, findings of the conducted research might catch attention of scientist dealing inside social studies and even transportation engineers.

The submitted paper can be considered as a foundation of the development of the Building Occupant Transient Agent-Based Model (BOT-ABM). The development process of a comprehensive model that is capable of simulating building usage in individual scale requires an extended period of development. The description of the movement module elaborated in this paper has to be considered as a part of the entire model. Additional modules of the entire model that will follow in next development steps, will use this paper as a reference. Aim of the BOT-ABM model is to re-evaluate the energy-related occupant behaviour simulator and apply it together with the existing software’s for building performance simulations. Therefore, we think that this publication fit into the journal scope and research interest.

Due to the lack of the native English speaker author in a team that was responsible for the development of this paper, we decided to use a commercial language editing service. We can provide a certificate of language editing if it is necessary

After receiving the comments from the reviewers, from the previous submission, we have noticed that our manuscript could be considered as difficult to understand for the readers. Therefore, we have addressed all given comments, that we hope will improved readability of our manuscript. The answer to all reviewers comments is included below.

#3: Dear Authors

Your research is out of the topic of Applied Energy: human movements in space not have a role in human comfort and/or building energy performance; maybe they have a role in human metabolism.

Dear Reviewer #3, thank you for your comment. Our motivation for submitting this paper was to fit it in the special issue e-CPS. From highlighted subjects included in a special issue description, we consider our research topic to fit to the subjects like:

- Learning and control strategies to improve e-CPS performance (energy efficiency, resilience, and human-centric services)
- Design, optimisation and data-driven modelling of energy systems
- Novel sensor methodologies, techniques, and tools that enhance the energy efficiency, energy reliability, durability and comfort
- Human-building interaction, personalised control, self-tuned environments
- Modelling, simulation, optimisation, and control of heating, cooling, lighting, ventilation, water usage and other resource flows in built environments.

Human movement is directly related to human metabolism, but it is also highly related to human comfort. Humans perceive comfort in the particular place and time, where the dynamic interaction between disturbances and HVAC system counteractions provides specific conditions. Actual indoor parameters have to fit into the occupant acceptance range. If not, most likely, occupants will try to change the condition by an action that always will involve some kind of movement, e.g. towards the thermostat or window. As described in the final report of the International Energy Agency, Programme for Energy in Buildings and Communities, Annex 66, every single human indoor activity has an impact on a building energy performance. Therefore, if occupants adjust the HVAC settings according to their preferences, they will influence the building energy performance.

Reviewer #4: The paper lacks concision. In particular, the abstract is much too long and not well formulated. The introduction contains unwarranted and excessive criticism about previously published research, e.g." there are no available models that are capable of simulating occupant actions (...) with the proper resolution". The claim that a time resolution of 1 second would be necessary does not build on any clear scientific evidence

Dear Reviewer #4, thank you very much for this comment. We agree that the previous version of the abstract and introduction section were difficult to read and they could confuse the reader. Therefore, we have made significant changes in both sections to improve its quality. We must acknowledge that the tone of our criticism should be lowered. In the way it was placed, it questions the development of all previous models. Which was unintended in any way. Our goal was to point out that in the current model stock, there are no models that focus on description of the occupant at the individual level, in a time resolution that matches their actions. The claim regarding one second of time resolution is based on a conclusion drawn by Da et. al. Energy and Buildings (2015) paper. Similar concussions are backed by Bing et. al. Building simulation (2019). Our motivation was to address conclusions of the previous research and build a model that operates in such temporal resolution. Ability to simulate occupant in such a time frame can deliver a deep inside information about their behaviour and explore the reason for their particular actions. Additionally, an operational resolution is significantly easier to downscale then to upscale. A simulation that operates in high temporal resolution can include more sophisticated actions, were upscaling low temporal resolution would rather be an action approximation.

We address all of these comments inside our manuscript, and we have changed both the abstract and the introduction section.

Reviewer #4: The presented model is not well documented in its mathematical functions and is probably too detailed for the purposes of building simulation.

Dear Reviewer #4, we understand your concern, and we have included in the text below the core movement simulation code. The same functionalities of the code are explained in the methods section of the manuscript. We have also added the graphical representation of the iteration steps of the movement simulator (fig.02), to make the model explanation more accessible for the reader. However, if you mean that this is still not sufficient, we can also develop an additional block model that represents simulation steps.

Input Arguments

Poly –polygon of simulation; *Start_Poss* – Start position; *End_Poss* – Goal position;
F_Ang_Cd - Angular cumulative distribution function;
F_Step_Cd - Movement speed cumulative distribution function;
Fq_Time – operating time resolution; *I_T* – Initial turn; *i* – Iteration step; S_i - iteration step position;
T_i - iteration turns; *Rand* – random number (0-1); *Eq_Pt* – equial distance selector;

i=1

T_1= I_T

S_1 = Start_Poss

WHILE $\sqrt{\left(\boldsymbol{S_i(x) - End\_Poss(x)}\right)^2 + \left(\boldsymbol{S_i(y) - End\_Poss(y)}\right)^2} > \frac{\boldsymbol{F\_Step\_Cd(Rand)}}{\boldsymbol{Fq\_Time}}$;

i=i+1;

Step_Distance= F_Step_Cd(Rand)/Fq_Time;

Step_Turn= F_Ang_Cd(Rand)

Test_T_1 = T_{i-1}-Step_Turn

Test_T_2 = T_{i-1}+Step_Turn

Test_S_1(x)= S_{i-1}(x)+ Step_Distance +cos(Test_T_1)

Test_S_1(y)= S_{i-1}(y)+ Step_Distance +sin(Test_T_1)

Test_S_2(x)= S_{i-1}(x)+ Step_Distance +cos(Test_T_2)

Test_S_2(y)= S_{i-1}(y)+ Step_Distance +sin(Test_T_2)

IF TEST_S_1 *inside* Poly

Dist_Test$_1$ = $\sqrt{\left(\boldsymbol{Test\_S_1(x) - S_{i-1}(x)}\right)^2 + \left(\boldsymbol{Test\_S_i(y) - S_{i-1}(y)}\right)^2}$

ELSE

Dist_Test$_1$ =Inf;

END

IF Test_S_2 *inside* Poly

Dist_Test$_2$ = $\sqrt{\left(\boldsymbol{Test\_S_1(x) - S_{i-1}(x)}\right)^2 + \left(\boldsymbol{Test\_S_i(y) - S_{i-1}(y)}\right)^2}$

ELSE

Dist_Test$_2$ =Inf;

END

IF Dist_Test$_1$= Dist_Test$_2$ & Dist_Test$_1$ = Inf

Redo_step= Redo_step+1;

i=i-Redo_step;

ELSEIF DIST_Test$_1$= DIST_Test$_2$

Redo_step=0;

Select_S= Dist_Test(Ee_Pt(rand));

S_i=Test_S(Select_S)

T_i= Test_T(Select_S)

ELSE

Redo_step=0;

Select_S= min(DIST_Test);

S_i=Test_S(Select_S)

T_i= Test_T(Select_S)

END

END

i=i+1;

S_i = End_Poss

It is challenging to evaluate if a model is too detailed or not. Building performance simulations software's are now aiming towards more precise descriptions of its features. Such a situation is observed thru the past two decades. New functionalities are enriching our knowledge and abilities to accurately represent building energy performance. A decade ago, under the first transition from CAD to BIM software's, it was unclear where and how it will contribute to the building energy performance simulations (BPS). However, right now, usage of BIM in BPS is a standard. The same might happen in this situation. In current state-of-art BPS software's there is no place for occupant movement simulation, but each new version of BPS software's introduces new features that support practitioners with tools that enables development of more accurate simulations. We believe that our model could contribute to the same target.

Reviewer #4: On the other hand, the presented example misses the important issue of large office rooms.

Dear Reviewer #4, our model application can be fully scalable because it operates in polygon representation of the floor. This was explained in methods, and results section. There is no difference in terms of movement simulation. If the layout representation is available, it will operate on it. Coordinate point localization will be conducted following the same principle.

Reviewer #4: The link with energy in general, which is important for publication in this journal, is not established.

Dear Reviewer #4, thank you for this remark. We noticed that such a link was not well expressed in our manuscript. Therefore, we provided few changes in conclusion section, to establish this link correctly and to make it more accessible for the readers.

Sincerely

Authors

Editing Certificate

This document certifies that the manuscript

BUILDING OCCUPANT TRANSIENT AGENT BASED MODEL- Movement Module

prepared by the authors

Jakub Wladyslaw Dziedzic, Da Yan, Hongsan Sun, Vojislav Novakovic

was edited for proper English language, grammar, punctuation, spelling, and overall style by one or more of the highly qualified native English speaking editors at AJE.

This certificate was issued on **April 5, 2019** and may be verified on the AJE website using the verification code **AE9B-BF2C-C3AE-CFC9-1B89**.

Neither the research content nor the authors' intentions were altered in any way during the editing process. Documents receiving this certification should be English-ready for publication; however, the author has the ability to accept or reject our suggestions and changes. To verify the final AJE edited version, please visit our verification page at aje.com/certificate. If you have any questions or concerns about this edited document, please contact AJE at support@aje.com.

BUILDING OCCUPANT TRANSIENT AGENT-BASED MODEL - Movement Module

Comment [JWD1]: Editor: Q3.3

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Abstract

Simulation of occupant behaviour (OB) ~~inside a building~~in buildings is a challenging task. ~~Currently, available~~Available software uses a broad spectrum of tools that try to reproduce the patterns of human activity. From building energy perspective, the main emphasis in research has been focused on discovering behaviour directly related to energy. In recent years, more attention has been given to simulating occupant actions that are indirectly influencing building energy use. In most of the cases, this is achieved with the use of ~~the~~ agent-based modelling~~ (ABM) technique. Currently, it allowed~~, which allows describing occupant actions on ~~the~~a room level. According to the ~~already~~ existing methodologies review, it is a proper step, but to include ~~OB~~occupant behaviour in energy simulations, spatial and temporal resolution of the ~~OB~~occupant behaviour model ~~has to~~must be improved. Addressing this issue requires the development of ~~the~~a comprehensive model supported by numerous modules that would cover various significant occupant actions. This paper focuses on the development of the high-resolution, data-driven movement engine of occupants. It is one of the fundamental modules necessary to simulate ~~the~~occupant behaviour with high granularity~~ OB~~. Once the~~ whole~~ model is developed within its essential functionalities, it will deliver a bottom-up model capable of testing various energy use strategies. It will allow for testing different ~~HVAC~~heat, ventilation and air conditioning solutions and ~~its response that is~~the responses provided by simulated occupants. ~~Data~~The data used to develop this module was obtained thru in-situ measurements, with the use of ~~the~~ depth registration~~ technique~~. Information obtained from experiments ~~are~~is similar to~~ the~~ previous research, but it also extends the investigation scope with an additional transition-based variable.

Comment [JWD2]: Reviewer #3. Q1
Editor: Q3.3
Editor: Q3.8
Editor: Q3.12

1. Introduction

1.1 Background

Building performance simulation ~~tools are commonly~~is a common tool used ~~during~~in the ~~building~~ design~~. Due to the numerical capabilities~~ phase of ~~modern workstations,~~a building. These tools make it ~~is~~ possible to investigate ~~various solutions and select~~several scenarios for the design ~~most~~conditions and select the one best suited to the given ~~conditions. Use of those applications enables conducting series of simulation trials to predict future operational energy use of the building. Such an amount of~~ situation. The information ~~during the design allows optimising~~provided is with the results of these simulations makes it possible to optimise the overall energy~~-~~-use of the planned building. ~~For example, if the~~The energy performance ~~target is set on~~of a ~~passive~~ building ~~standard, it~~ is ~~possible to investigate what kind of measures must be applied to achieve the specified goal. The success of predicted annual building energy performance (after the building has been constructed), relies on numerous~~influenced by several factors~~. Many aspects may influence the design target~~, such as ~~proper~~ construction ~~or~~faults, setup of the ~~building management system.~~Building

Management Systems (BMS) etc. To achieve an accurate design target with the simulation tools, it is necessary to take all the influencing factors into account. Even ~~if~~after accounting for all ~~design steps are fulfilled correctly~~these factors, the ~~success of reaching the desired~~ energy ~~target~~performance eventually relies on the ~~assumptions regarding the~~ building ~~users. As shown in a~~occupants. A study conducted by Turner [1~~],~~] shows that only 30% of the analysed buildings have similar operational and simulated energy use. Based on~~ the~~ previously conducted research [1], such a mismatch between simulation and commissioning results might be caused by oversimplifying the factors like: occupant behaviour, construction quality, weather profiles etc~~., in general energy calculations~~.

The significance of the behaviour of building occupants on energy use has already been acknowledged. The description and foundation of current indoor environmental standards (ASHRAE 55 [2]) ~~is~~was made half a century ago by Fanger [3]. Since this~~ scientific field~~ milestone, the work on this subject continues to this day. The recently finished IEA EBC Annex 66 ~~delivers~~delivered a significant contribution to this field by organising knowledge that already exists~~, providing~~ and provided organisation and instruction for the next steps of development [4], [5]. The final report of Annex 66 [5] ~~points~~also pointed out that newly developed models should aim towards the ~~individual level of~~ occupant description on an individualistic level. Additionally, such models should be able to simulate various occupant indoor activities. Based on existing ~~knowledge, modelling of~~literature, occupant behaviour (OB) is usually represented as a stochastic process [6]. It means that each conducted action is assumed to have its reason and can be explained, although the accumulation of ~~a~~ similar, registered activity can formulate ~~operational~~particular distribution. The same action cannot be conducted under the same conditions: that is why its repetition might generate certain variations in performance or instruction in reaching a similar goal. The repetition might generate a sensation of the randomness of the observed action, but it is not the operational driver of the action. Direct OB cannot be considered stochastic due to the deterministic nature of the actions of the occupants. That is why the actions of building ~~users~~occupants should be analysed holistically to highlight the ways of reaching a similar target, which can later be extracted into the description (recipe) of achieving the goal. The only exception in forming the spectrum of possible behaviours is irregular behaviour [7].

1.2 Challenges in OB modelling

Indoor OB is a complex phenomenon. Therefore, development of ~~the~~a functional simulator is an iterative process, and it requires access to various data sources. Conducted study by ~~Da~~Yan et al. [8] reviews, segregates and evaluates performance of OB models. In this study, many existing models are considered. Evaluation of the models took into the account three resolution criteria (temporal, spatial and occupational). Some of OB models that were considered were models already implemented in~~ a~~ BPS software like Energy Plus [9], [10], IDA-ICE [11], [12] or De-ST [13], [14]. C. Wang et al. [13] application was not taken into account in this review, but its contribution was already implemented in a DeST software while performing the review. One of the most accurate models has reached a temporal resolution of ten minutes and a spatial resolution that allows simulating the zone occupancy state [9]. Description of the zone occupancy state can be considered as a good enough, but as ~~it was~~ pointed out by ~~Da~~Yan et al. [8], it does not allow for re-creation of the behaviour of the individual occupant. ~~As it was concluded, newly~~Newly developed models ~~should~~need to aim towards higher resolutions of occupant description and better robustness.

Similar conclusions can be found in the work of ~~Bing~~Dong et al. [15]. As ~~pointed out there~~that study highlights, no solutions promote integrity or a broader framework for a spectrum of applications. Most of the models developed in this field are ~~focussing~~focused on presence of occupants, counting of occupancy, operation of windows, operation of blinds, operation of indoor lights, HVAC sizing and ~~the sensation of~~ thermal comfort, crowd and security simulations, and design of building installations [15]. Usually, each model ~~focuses~~focused on one particular phenomenon related to ~~the~~ OB. Proposed by Gaetani et al., the method ~~for~~of segregation of the models ~~seems to be a correct step~~is one of the plausible steps towards

Comment [JWD3]: Reviewer #3. Q1
Editor: Q3.1
Editor: Q3.12

the development of a communication platform [16]. Categorisation of the models in such a fashion proves that there are no universal models and the topic of energy-related OB in the building is complex phenomena.

1.3 Use of ABMs for OB

Based on provided evaluations, the new OB model requires changes in the observation of occupant actions in buildings. It is assumed that an extension of the observed spectrum of OB by new measurement techniques can improve the quality of the model. Following the conclusion delivered by Yan et.al. [8] and Dong et al. [15], the newly developed model has to operate at the same time duration, as actions conducted by occupants might last. The same principle must follow the spatial localisation of their activity. The result of such measurement might produce additional noise to the data, but it ~~should~~will allow capturing reasoning for the actions that occupants conducted. Therefore, the occupants must be identified correctly in the BMS system and properly described, and the resolution of the data collection should allow for capturing the smallest significant event [16]. If such requirements are fulfilled, it is possible to process the data that have been gathered without losing any context from each registered activity and to gain in-depth knowledge of the observed subject. The main challenge related to this approach is its significant difference between operational temporal resolutions. Occupants conduct their actions in a temporal resolution of a second (or even less), where a noticeable reaction on a condition may last many minutes or more. The difficulty is simulation scaling. The cumulative sum of the actions of the occupant cannot be considered a significant approximation due to the dynamic nature of the behaviour of the occupant. Observed reactions to the given indoor conditions might be dependent on numerous factors such as thermal conditions, acoustic conditions, purpose of the occupation, and many more [17]. Therefore, activity sampling for the building occupant with the frequency of a second can be considered a sufficient operational resolution. Such resolution extension would address conclusion delivered by Yan et.al. [8] and Dong et al. [15]. High-resolution sampling should allow capturing each important event, from the perspective of the building occupants. Discretisation at that level leaves relatively small room for any potential misinterpretation. However, such hardware application requires delivery of the probed data in the least invasive way. Meeting such specifications can be considered a challenging task. Fortunately, such challenges were addressed in past research. Currently, it is possible to fulfil this requirement with inexpensive gears [18], [19], [20], [21].

Fulfilment of the requirements for the new OB model can be achieved with the use of agent-based modelling~~ technique~~. It is a promising technique that is capable of re-creation of occupant behaviour that meets the three resolution criteria. This modelling technique allows design of an artificial being (agent) that can operate in any given environment. The agent reacts to the given conditions, based on given targets and specifications. Additionally, the agent can deliver feedback for any condition, even those that are not pre-scheduled. The agent follows instructions from the delivered set of rules. Rules could be considered to be a habit or “personal” preference [22]. This modelling technique allows for introduction of the modular OB model where each module is responsible for one particular OB-related phenomena. This approach allows for description of the OB through the perspective of the occupant. Currently, there are agent-based models ~~that are ~~focussing on human reactions that have origins in a building occupant [23], [24], [25~~].,~~], but its granularity does not ~~much~~ catch up with future targets proposed by Yan [8] and Dong [15]. The ~~closest ~~applications that are closest related to human behaviour simulations are simulators that focus on ~~exploration of the public facilities, crowd management, pedestrian movement and ~~fire escape [26], [27], [28], evacuation pathway testing [29], [30], strategic and aid support [31], crowd management [32], [33~~], ~~] or pedestrian movement [34]. None of mentioned models put extensive emphasis on the development of a sophisticated description of the distinct person. The most advanced agent-based models ~~focus on functionality~~have functionalities such as agent age, sex, speed, maximum acceleration, body size, health and strength. Those functionalities are implemented in fire escape simulations [26]. With these parameters, it is

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possible to simulate complex fire escape scenarios with various placements of the fire origin. These methods are especially useful to test scenarios that aim to minimise causalities among exposed populations. This target can be obtained by different placement of sprinkler system, proper control of the smoke ventilation and crowd discharge columns. Similarly, other applications mentioned above were designed to investigate specific phenomena. It is noted that most ABM simulators of the OB are polarised into one of the two categories in terms of the temporal resolution. Most of the energy OB ABMs are aiming towards hourly simulations to capture the annual performance of the building. Another is more like an event-based simulation (like evacuation). Simulation timeframe does not last for a prolonged time, but its temporal resolution is close to capturing sudden occupant reactions.

2. Aim

Development of holistic OB models is already a well-known task in the research community [35], [36], [37], [38], [39], [40]. Nevertheless, a merge between precise (~~that~~ whole simulations that last for one particular event, with a high temporal and spatial resolution) and existing hourly models was not found in the literature. To connect those two approaches, it is necessary to divide the whole model into distinct modules due to the nature of its complexity. Each module has to communicate with other subparts and has to be reliable. Therefore, the development procedure has to be taken care of with extra caution and attention to details.

~~It seems that~~Based on existing literature it is necessary to develop a OB simulator tool that is capable of operating on high spatial and ~~temporary~~temporal resolution ~~OB simulator~~ that can also perform annual simulations. Its application should allow for a fit-for-purpose approach of OB simulations. With the proper tool, it would be possible to investigate various occupancy scenarios and test whether there is ~~a~~ space for potential optimisation of the building energy use. To address these issues, it is necessary to create a tool capable of conducting simulations that re-assemble the patterns of normal building usage. Such a tool must operate in an energy-cyber-physical system that might potentially be used during the design and operation phase of a building. The suggested tool should allow for a human-centric design of the building, where the existence of the ~~users~~occupants is not marginalised or oversimplified. The framework of such a model was described by Dziedzic et al. [41]. Progress towards such a goal must be initialised with a description of the basic functionality of the occupant. Each functionality will be referred to as a module.

The description of the actions conducted inside the room/zone by the occupants requires proper localisation. Information about the localisation state of the occupant might be used to describe the thermal preferences and actions that the person is engaged with. Thus, the initialisation point of the new occupant behaviour model should focus on the development of a solver capable of simulating movement indoors. This paper aims towards the development of the movement solver by analysing collected data through depth registration ~~technique~~. The developed solver ~~will be~~is a foundation for the new agent-based model. The primary purpose of this solver ~~will be~~was a simulation of individual transitions inside a known building layout. It is assumed that the layout of the simulated zone is known, and the agent also recognizes starting and finishing points. The agent ~~has to~~must generate pathways similar to the natural transition of the occupant. Therefore, the created pathway will not be optimal, nor the shortest. Such algorithms are already existing.

3. Methods

3.1 ~~Access~~Collection and access to the data

Development of the movement simulator ~~must~~needs to rely on data obtained during the *in-situ* observation of the natural transitions inside the building. With the use of depth registration camera, it is possible to obtain this information. This technique allows observation of a surface in a space using an infrared projector and camera that allow monitoring a reflection of the projected beam. Collected information can be transferred into

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the raster map, where separate pixels hold information about the distance of the monitored surface. A static picture can be treated as a background. Any obstacle that crosses the monitored area will be distinguished from the background and treated as a dynamic object. Cover range and accuracy of this camera are directly related to the image amplifier that has been installed in camera. There are many available devices on the market capable of conducting such measurements. In terms of application readiness, one of the most popular cameras is the Microsoft Kinect v 2.0 for Windows [42]. Due to these reasons, this device was selected ~~for conducted~~to be used in experiments. Access to the data and its applications was well described by Dziedzic et al. [20]. In short, the selected device transfers a humanoid-like shape into a built-in skeleton model (SM). The SM is a twenty-five-joint model, where each joint ~~matches~~match up with a designated place on a humanoid body. For example, if the joint should be located at the base of the spine, the SM will try to estimate its position based on an observed shape. Each joint is described by four variables, three-dimensional information of the distance from the device centre point, and global clock information. Collection of the information from all joints can be used to formulate principles of the movement simulator.

Data collected through ~~a~~ depth registration ~~technique~~ requires some amount of post-processing. With proper software tuning, it is possible to keep the data collection procedure in an infinite loop. Due to the hardware limitations, each procedure might collect a number of “frames” until the computer buffer memory runs out of space. To avoid this situation, each package of collected frames is transferred to the hard drive, which requires a temporary pause in the depth data acquisition. Consequently, ~~some pieces of~~ if occupant was performing a transition while data ~~could~~was transferred to hard drive, few frames of this transition might be ~~missed~~unregistered. To bypass this condition, double registration of the same scenario is required. Such a procedure minimizes the possibility of missing any potential activity. The number of collected frames is limited by the hardware calculation capabilities that are used. Data used during the development of the movement simulator module were accessed from the compilation of previously conducted research. Each participant in the experiments was adequately informed about the quality and quantity of collected information. All the participants gave their consent to collect and process data obtained with the use of the depth-registration camera. Therefore, the research that was conducted did not cross any ethical boundaries.

3.2 Data ~~post-processing~~Processing

Collected information about occupant activities must be post-processed in two steps: projection surface recalculation and pathway clustering. ~~A~~The device used in ~~experiments~~the experiment defines a local coordinate system. The position of the device and its angular position influence the data collection process directly. Fortunately, it is a repetitive error that can be eliminated by ~~the~~a transformation matrix that straightens the observation angle. Information about the transformation surface can be obtained via analysis of selected joint SMs. Use of joints that are not contributing significantly to the pendular movement of the human body is recommended, ~~for~~due to stability of the readings. For example, any of the joints that describe the spine. Analysis of this spot allows a description of the operational surface, where all measurements must be re-calculated to estimate the height-axis transformation vector. Points from the foot joints must be projected on an operational surface, and an average distance must be set. Once the data are calibrated to represent movement on a straight floor surface, it is possible to proceed with the next post-processing step.

A set of the whole number of points acquired during a measurement procedure can be connected in a formulation of the single pathway. To distinguish each pathway, it is necessary to apply a classification technique. Due to the ~~significance~~significant amount of the recoded movement, it is necessary to use an unsupervised segregation technique. Additionally, the deployed processing methodology must be capable of connecting the missing pieces of movement records that occur during the temporary pause mentioned above. To fulfil all the given restrictions, a modified density-based scanning method (DBSCAN) was deployed. The principles of formulation of DBSCAN were introduced already in the 1970s [43], but back at that time, it did not attract too much attention. In recent years, this method has gained increasing applicability due to the ability to use it in the unsupervised cluster spatial data series. The method mentioned operates on two operators (~~alfa~~alpha and epsilon) that must be set according to the data granularity. Operator alpha describes a range of the investigation spectrum of ~~a~~the point that is currently being considered. Operator epsilon controls how many points inside the alpha range must be included to consider such ~~a~~ data set as a cluster. This method is ~~an~~ efficient in detection of complex shapes and ~~de-noised~~denoised data sets. According to this DBSCAN description, this method does not require ~~the~~ definition of observed clusters. Therefore, there is no need to keep track of how many paths this clustering method must detect. To correctly detect ~~belonging to~~classification of the given cluster with the use of this data type, it is necessary to introduce an additional dimension where temporal distance plays an important role. Otherwise, most of the collected data points will belong to the same cluster due to the spatial overlay. Introduction of the time parameter as an alpha variable block under classification enables data connection due to the temporal data acquisition.

3.3 Development of the movement solver

Segregated data sets were analysed to capture movement statistics. In this step, each detected path was processed separately. Each point in the recorded pathway was considered, except for the last step point. Statistical analysis ~~must include~~included parameters such as movement speed distribution, and movement angularity distribution. Observation of the movement speed ~~can be~~was done by direct calculation of the distance between the present step and ~~the next~~following step ~~and dividing this value~~divided by the amount of time ~~that it took~~between these two points. The second parameter was the movement angularity distribution. If each point can be considered a local Cartesian coordinate system, each next point formulates a corner with an x-axis, which has its angle

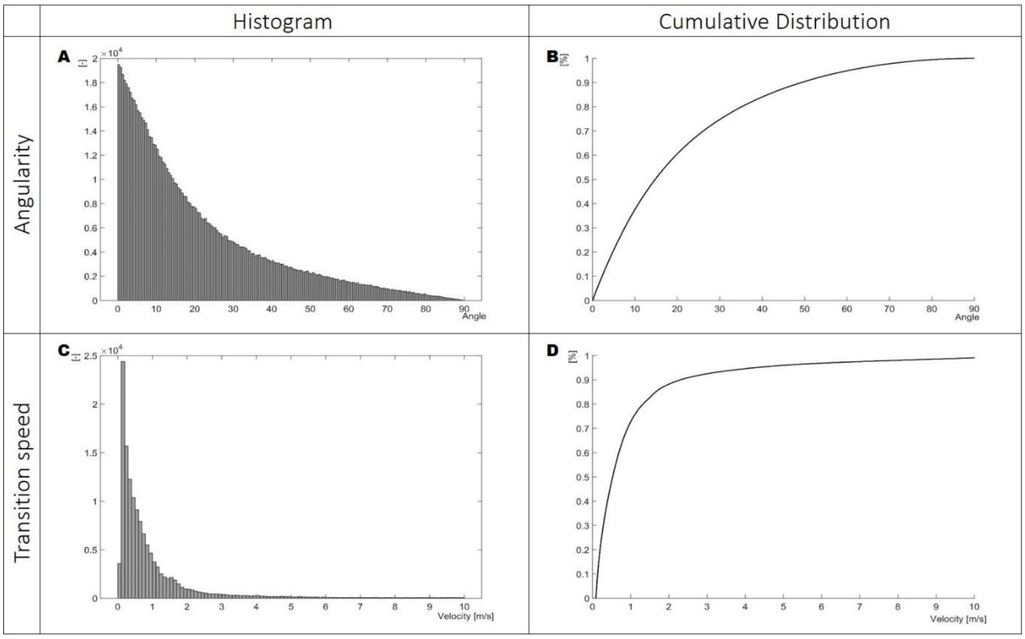

Figure 1. Movement and Angular distribution of used data sets. Cumulative Angular Distribution (CAD) and Cumulative Velocity Distribution (CVA)

value. The difference in the angle value between the present and previous step can be considered an angular movement fluctuation. These values aggregated in summary of the whole movement ~~can be~~are considered a movement angularity distribution, which ~~can be~~are processed later. The results of all investigated distributions are shown in ~~figure~~Figure 1.

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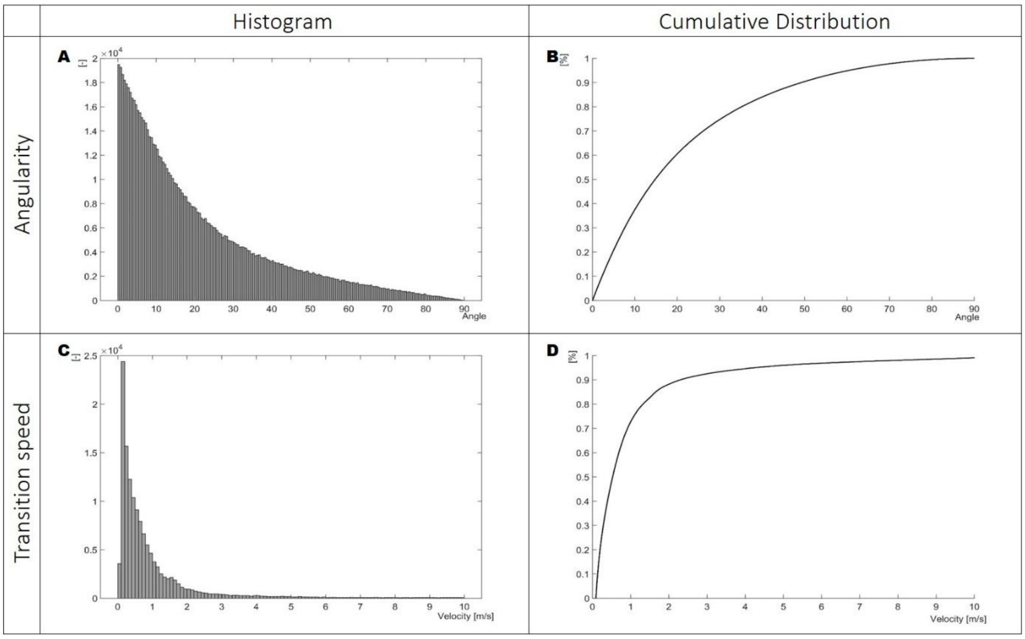

~~*Figure 1. Movement and Angular distribution of used data sets. Cumulative Angular Distribution (CAD) and Cumulative Velocity Distribution (CVA)*~~

As shown in ~~figure~~Figure 1A and ~~figure~~Figure 1C, both distributions show a particular pattern of movement of the occupants. Most of the observed transitions of most of the movements are conducted at a speed between 0,5 - 2 metres per second. In terms of the angular distribution, there were no transitions that required a larger angular difference than 45° in one step. Analysis of the step progression did not show any significant proof that there is a pattern, where step speed accelerates in a particular phase of transition. Both~~ of the~~ variables were tested in terms of the correlation between each other. Surprisingly there is no correlation (correlation value of 0.015) between step velocity and angularity. It is a counter-intuitive statement, but there are no proofs to claim differently. Both speed and general angular distributions ~~can be~~are formulated ~~by a~~into cumulative distribution function where the order of sampling is dependent on the lowest to the highest value. Once both distributions are transferred into a cumulative distribution, both newly formulated curves ~~can be~~are described by the function using ~~the~~ polynomial regression. ~~Delivery~~Obtained distribution function formulas ~~can be~~are used as a basis for the simulator development. Using the random function as a solver, it is possible to obtain access to the variable values from both cumulative distribution functions (speed and angular distribution), allowing for a simulation of the transition steps. Additionally, the obtained cumulative distribution of movement speed matches with the previously generated distribution ~~form~~from conducted research that used GPS data [44]. As an additional novelty, it ~~has to~~must be pointed out that with use of the depth registration camera it was possible to obtain a cumulative angularity distribution, that was impossible to generate with previously used measurement techniques due to is small spatial accuracy.

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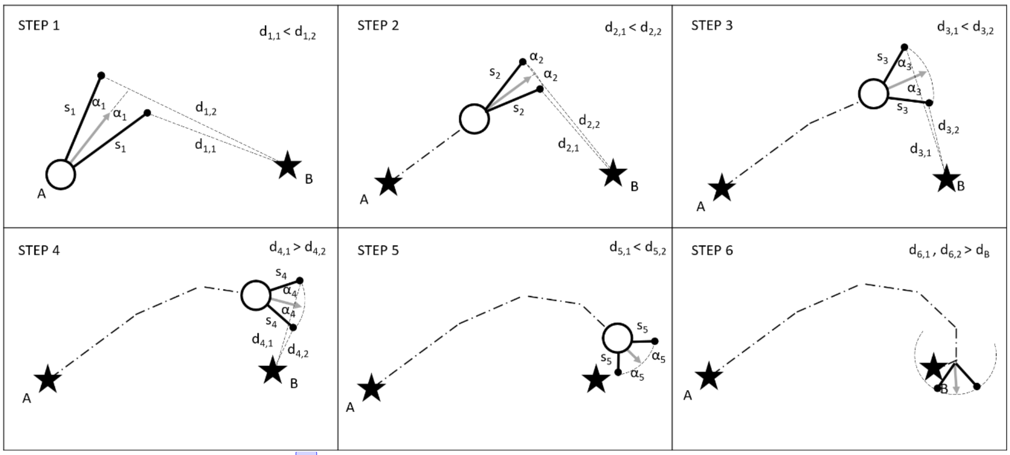
To simulate the movement of an agent, it is necessary to give it a selected target for a transition towards which it can aim. To do so, the room coordinate system ~~must be~~is developed, and ~~it~~its development will be explored in the following text. Each time when a new step is updated, the agent moves following the vector generated in a previous step. Each time the agent is re-solving a selection of the step parameters, it updates its distance and angular difference from the turn of the previous vector. The side of the angle differential is selected by estimation of the future position from both sides of the previously followed vector. Both points are tested in terms of the distance from the aimed target. The shorter distance from both of the projections selects which is the following step position. Solving the dilemma at equal distances will be addressed in the following text. The sequence of pathway selection



is illustrated in ~~figure~~Figure 2.

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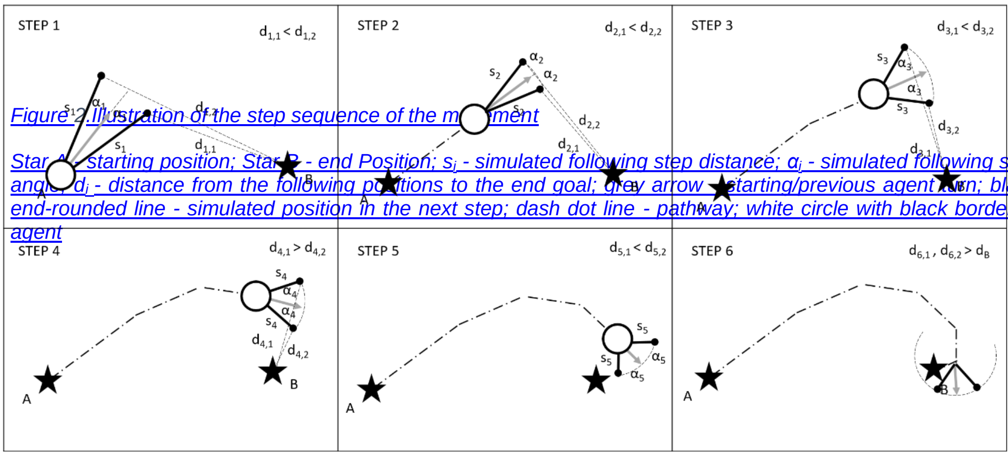

Figure 2.Illustration of the step sequence of the movement

Star A - starting position; Star B - end Position; s_i - simulated following step distance; α_i - simulated following step angle; d_i - distance from the following positions to the end goal; grey arrow - starting/previous agent turn; black end-rounded line - simulated position in the next step; dash dot line - pathway; white circle with black borders - agent

~~*Figure 2.Illustration of the step sequence of the movement*~~

~~*Star A - starting position; Star B - end Position; s_i - simulated following step distance; α_i - simulated following step angle; d_i - distance from the following positions to the end goal; grey arrow - starting/previous agent turn; black end-rounded line - simulated position in the next step; dash dot line - pathway; white circle with black borders - agent*~~

3.4 Floor layout and coordinate detection

The solver that has been developed can simulate any given step re-creating the natural distribution of steps taken. To transform the designed solver to a form applicable for BPS, a definition of operational space is required. To do so, it is necessary to develop a grid of connection that represents a floor layout structure, that is used for this simulation. Obtaining the connection grid ~~must be~~is generated automatically for any given investigated space. The source data for investigated space ~~can originate~~originates from a vector polygon drawing or a raster picture. If the layout is defined using the vector polygon, there is no need to prepare the layout for further processing. If the delivered information about the floor layout is available only in a raster picture, it requires further pre-processing. The raster picture of the floor layout ~~must be~~is transferred to its binary representation, where the space representing floor layout has a value equal to one, and the rest of the features (such as walls) have a value of zero. The first step towards vectorization is the detection of the corners and outline of the given layout. Outline and corners ~~must be~~are located from both the inner and outer sides of the layout, allowing for simplified further processing. If the emphasis on outline detection was put in one of the sides, it could potentially generate a formulation of pixel "stairs" that would complicate ~~the~~ further calculations. Side outline points located on the inner side have surrounding five positive pixels. On the outer outline, side points have a sum of three surrounding pixel. Correspondingly, for the corners, the inner outline is four, and the outer outline is one. Detection of the whole set of the pixels on edges on the floor layout allows for a formulation of the layout pixel set, ~~which can be~~that are analysed by ~~the~~ DBSCAN ~~technique~~ to classify all the selected pixels. If the clustering technique detects only one cluster, it means that there are no more non-connected outlines, which implies that this specific layout has no "holes" inside the layout. If there are more clusters detected, the vectorization process requires one additional following step. Access to the vector description is essential for the general reduction of the processing time of the movement simulator. Operation on a vector requires significantly less computational time than the constant recalculation of the high-resolution raster picture. Therefore, pre-processing of the raster type input ~~must be~~is addressed properly.

Each outline cluster detected ~~can be~~is described by the continuous sequence of points representing corners in a selected order (clockwise or counter clockwise). The last points are the same as the first, to close the entire loop. Because each corner was represented by two points during the detection process, from each pair of the mutual corner points, only one was used in the following process. Each corner point that has a value of one was used during the outline segregation procedure. The formulated outline sequence is directly transformed into the vector polygon. To check the quality of the vectorisation procedure each pixel that represents layout, ~~has to be~~is catalogued by its localisation value. If the sum value of all the points included inside the polygon, is equal the total amount of catalogued points, it means that the polygon was detected correctly. If it is smaller, it means that there are holes inside the formulated polygon area, and its localisation has to be re-addressed. The same process of corner sequencing continues for each detected cluster. If the detected cluster, translated into polygon has a total amount of catalogued points equal zero, it is a definite "hole". Each detected "hole" is subtracted from the main polygon area by the Boolean operation. This process continues until the main polygon is formulated properly and passes the quality check test. This process assumes processing of one zone/room that does not allow for a formulation of the multiple "only positive" zones. If there are multiple starting clusters, the main starting cluster is selected by the largest initial area, before Boolean reduction of the space size.

Once the vector description is available, it is necessary to extract information about all the vector corners to initialize the process for automatic detection of the coordinate system. Each corner is being paired with others included in the set to position midpoints between connections that are capable of “seeing” each other without obstacles. ~~The probing line is detecting the obstacles.~~ The probing line is a set of artificially generated points on a line connecting two corner points, where the points are generated by the number of even divisions of the connection line. This probing line is responsible for detecting the obstacles. If there is any point from the probing line that is not included inside the polygon area, it means that this pair of corners is not visible by each other. Therefore, the midpoint is not formulated between these corners. This process of detection is illustrated in ~~figure~~Figure 3. All the midpoints that are included on the edge of the polygon are not included in a further step. Each midpoint that is included in the main set obtains its individual fixed number.

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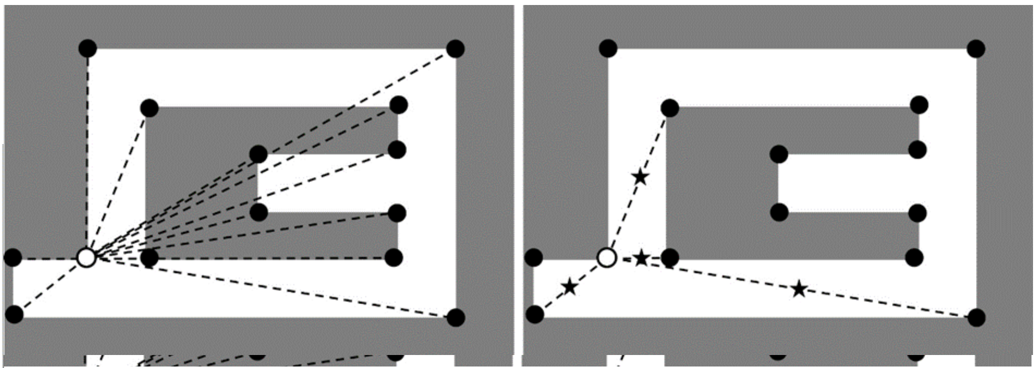
The set of all midpoints ~~is being~~has been tested according to the same principle as in the previous step. With the use of the probing line, midpoints are investigated in terms of the visibility to each other. Each visible midpoint highlights its visibility by marking it in a connection matrix (CM) for the other. This matrix is responsible for the formulation of the relationship between midpoints. It has a size of n*n, where n is the number of midpoints included in this analysis step. Each time there is a visible connection between two points, CM updates its status by giving value one to the cell that is represented by the row/column and column/row for both points. CM is symmetrical. Once the whole set of midpoints is tested in terms of their ~~vicinity~~visibility to each other, CM ~~can be~~is tested in terms of its potential for simplification. Each row that has a unique set of other connections is kept for the final version of the CM. If there is a row of connections that has the same set of connections but fewer connections than its comparison with other points, it is removed from the final version of CM. The result of this removal is that the amount of points is reduced to the necessary minimum. All the points included in the final CM will be used as main coordinates for the movement of the agent inside the selected layout.



~~Figure 3. Examples of coordinate point’s detection~~

~~Grey area - walls, obstacles, non-transparent features; white area - floor area; white circle - investigated corner; black circle - all the other corners; dashed line - connection to the different corners; star - detected coordinate points~~

Figure 3. Examples of coordinate point’s detection

Grey area - walls, obstacles, non-transparent features; white area - floor area; white circle - investigated corner; black circle - all the other corners; dashed line - connection to the different corners; star - detected coordinate points

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3.5 Transition simulation

Simulation of the movement requires the definition of the start and the end points. For the purposes of the test, start (A) and end (B) points are being generated randomly inside the floor layout. Before the transition process can be initialized, the solver must select a set of CM to generate a pathway connection. The pathway between A and B must be established with the use of the coordinates from the final CM. The driving force for optimization of the pathway will currently be a distance. The root optimization will be done with the Dijkstra's shortest path routing algorithm [45]. This method delivers the shortest pathway based on a wage connection system. The generated matrix of connection will be re-calculated into the distance connection matrix, where each cell represents the distance between corresponding points from CM

Once the shortest pathway is selected, it is exported as a vector holding an instruction of coordinate points that an agent must follow to reach the final destination. During each step, the agent updates its aimed target of the corresponding point. If there is a visible corresponding point that is farther in the progression on a direction vector, the aimed target is updated, and the agent progressively continues generation of the next movement steps. If the simulated step will cause moving out of the layout polygon, then the step is re-calculated until the placement of the next step is not correct. The movement simulation continues until it is not in the last step distance to the selected target. If the agent can potentially reach the endpoint, then the movement simulations transition it to the final destination. Reaching the exact point of the pathway end would require a tremendous amount of ~~interaction~~iterations. It could potentially not reach a final point at all. That is why the direct step simulations stop in an iteration before the last step. In other words, there is an approximate destination point that the agent has to fit into to conclude the movement simulation process.

Simulation of more than one occupant can be done using the same solver. Each agent representing an occupant can have its own pathway. If they meet in the same corridor or path, both the agents must switch sides, as it happens in real life. This situation might happen if the one agent is blocking the view of another to the aimed corresponding point. Each agent has its physical dimensions (width and circumference) that are implemented in the simulations. To simulate passing of the agent, each has an additional set of supportive corresponding points that can be dynamically included in other transition pathways vectors. A set of two supportive points is placed in a position perpendicular to the current vector turn. Each additional point is in a distance from the body centre equal to its circumference. If the agent blocks the aimed target, the software will update the pathway vectors. Included in that scenario, agents will aim towards a supportive point of another agent that is closer to them. This situation will happen if agents are opposing each other. If the agents are following a similar pathway, one will follow another until the previous target of the following agent is not visible. Simplified version of the transition algorithm is shown in a ~~figure~~Figure 4.

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~~*Figure 4. Simplified movement simulator algorithm*~~

Input Arguments

Poly –polygon of simulation; *Start_Poss* – Start position; *End_Poss* – Goal position;
F_Ang_Cd - Angular cumulative distribution function;
F_Step_Cd - Movement speed cumulative distribution function;
Fq_Time – operating time resolution; *I_T* – Initial turn; *i* – Iteration step; S_i - iteration step position;
T_i - iteration turns; *Rand* – random number (0-1); *Eq_Pt* – equial distance selector;

i=1
T_1= I_T
S_1= Start_Poss
WHILE $\sqrt{(S_i(x) - End\_Poss(x))^2 + (S_i(y) - End\_Poss(y))^2} > \frac{F\_Step\_Cd(Rand)}{Fq\_Time}$;
i=i+1;
Step_Distance= F_Step_Cd(Rand)/Fq_Time;
Step_Turn= F_Ang_Cd(Rand)
Test_T_1 = T_{i-1}-Step_Turn
Test_T_2 = T_{i-1}+Step_Turn
Test_S_1(x)= S_{i-1}(x)+ Step_Distance +cos(Test_T_1)
Test_S_1(y)= S_{i-1}(y)+ Step_Distance +sin(Test_T_1)
Test_S_2(x)= S_{i-1}(x)+ Step_Distance +cos(Test_T_2)
Test_S_2(y)= S_{i-1}(y)+ Step_Distance +sin(Test_T_2)
IF TEST_S_1 *inside* Poly
Dist_Test$_1$ = $\sqrt{(Test\_S_1(x) - S_{i-1}(x))^2 + (Test\_S_i(y) - S_{i-1}(y))^2}$
ELSE
Dist_Test$_1$ =Inf;
END
IF Test_S_2 *inside* Poly
Dist_Test$_2$ = $\sqrt{(Test\_S_1(x) - S_{i-1}(x))^2 + (Test\_S_i(y) - S_{i-1}(y))^2}$
ELSE
Dist_Test$_2$ =Inf;
END
IF Dist_Test$_1$= Dist_Test$_2$ & Dist_Test$_1$ = Inf
Redo_step= Redo_step+1;
i=i-Redo_step;
ELSEIF DIST_Test$_1$= DIST_Test$_2$
Redo_step=0;
Select_S= Dist_Test(Ee_Pt(rand));
S_i=Test_S(Select_S)
T_i= Test_T(Select_S)
ELSE
Redo_step=0;
Select_S= min(DIST_Test);
S_i=Test_S(Select_S)
T_i= Test_T(Select_S)
END
END
i=i+1;
S_i = End_Poss

Figure 4. Simplified movement simulator algorithm

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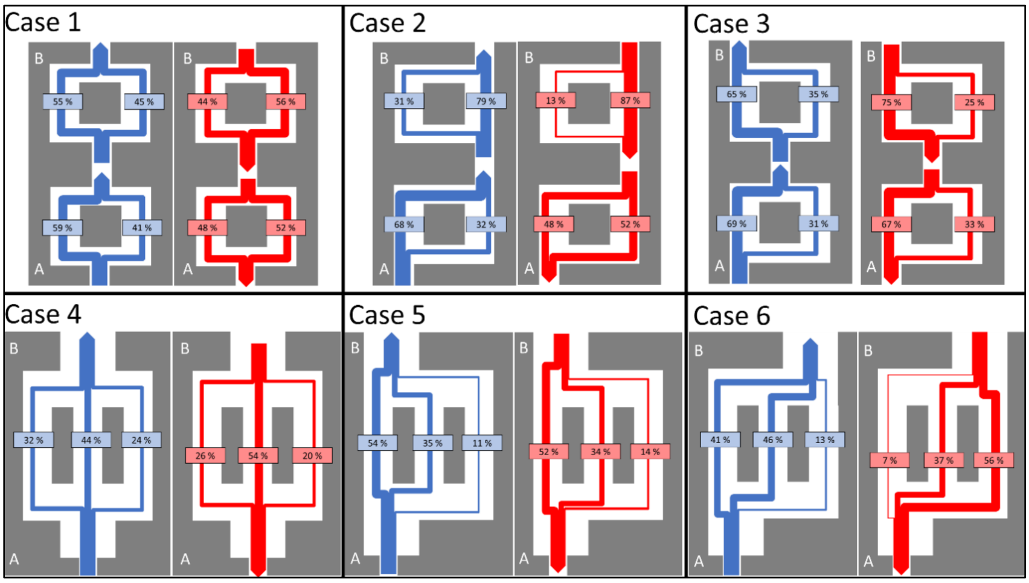
3.6 Even distance dilemma

During simulations, there is a chance that the agent will be exposed to conditions where it must select one particular direction. ~~Both~~If both the connections will be even in terms of the distance, or the simulated angular distribution will deliver an even distance from both sides to the aimed target. It could be possible to assume that the selection of the direction is random,

~~backing up~~but this ~~statement.~~solution has to be backed up by experiment. To investigate this phenomenon, a series of experiments ~~was~~were conducted, where, in an improvised maze, monitored humans ~~must~~had to select their transition. The whole experiment was divided into six series (cases), where each human had ~~its~~their unique maze layout (~~figure 4).~~ Figure 5). Each maze was created using office desks, allowing participants to screen the whole space. It is possible to assume that each participant was aware of the direction that it was aiming to. Different maze setups were designed to investigate the influence of the entrance/exit placement on possible pathway selection. Data from this experiment were captured using the two depth registration cameras capable of covering the whole maze setup area. In the experiments, ten participants were involved (seven ~~males~~male and three ~~females~~female). During the experiments, each setup had to be executed ten times at a normal transition speed. Repetition of each maze was performed to check if there is any influence of task repetition, where participants could lower their focus and perform actions that rely on their automatic response.

Collected data were analysed in terms of the path section selection. Each maze had its entrance, middle corridors, and exit. Detection of the distribution of a particular selection of the pathway was done by analysing the entrance/exit of the maze with a detection where the side of the maze was used to move towards another side of the maze. Therefore, one setup generated twenty decisions per person. The results of the collected data distribution are summarized in ~~figure~~Figure 5.



As expected, there is no particular correlation between the selections of the pathway, while all of them have a similar direction. If there is ~~an obvious~~a pathway that is ~~far~~obviously longer than a more straightforward pathway, in most of the cases, such pathway will not be selected. Nevertheless, it is not justified to discredit selection of the longer pathway. Therefore, obtained distributions regarding path selections were implemented into the movement simulator module.

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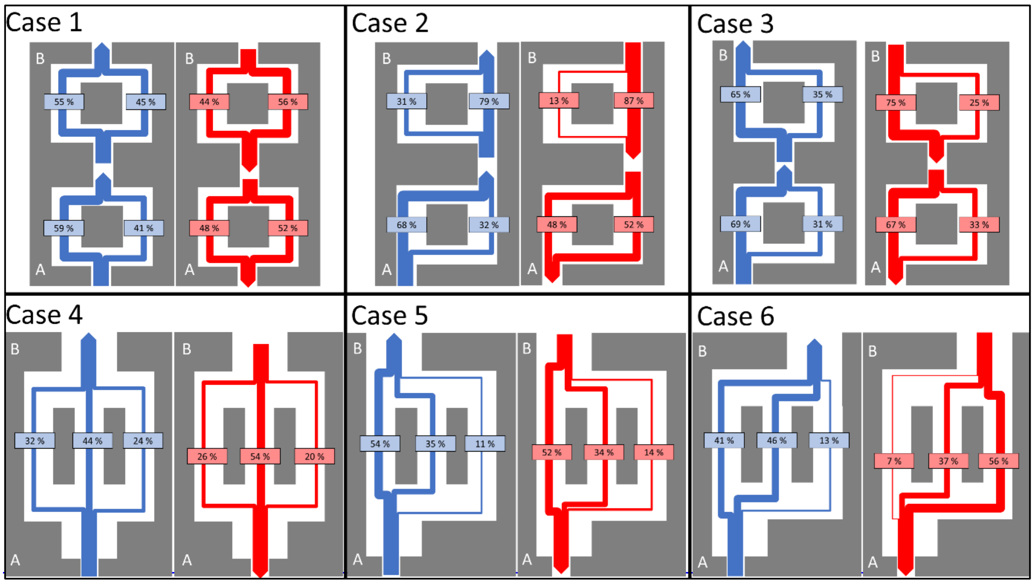

Figure 5. Movement transition experiment setup and transition vectors. Each case was analysed separately regarding aimed direction Each transition for A to B was coloured as a blue graph, and from B to A as a red graph

4. VALIDATION

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The developed model was validated by following commonly practised validation methods included in the existing literature [46]. To do so, it is necessary to identify the baseline of the phenomena and compare its performance with the following scores variables: "Reaching the target", "Too many steps", and "Outside layout". The whole simulator operates on a fixed time resolution. Therefore, the time variable can be neglected. If the agent reaches a goal, it scores on a " Reaching the Target" variable.

If the agent fails to transit into the target within ten times of steps (iterations) that in average are necessary (shortest distance divided by the average speed) the agent fails~~,~~ the transition. In such a case, the transition scores on ~~an " Outside layout~~a "Too many steps" variable and ends simulation in that spot.

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The developed module operates on ~~a~~the following five functionalities: cumulative velocity distribution (CVD), cumulative angular distribution (CAD), Shorter distance selector (SDS), floor layout detection (FLD), Even distance dilemma (EDD). Each functionality was described and defined in a subsection of the Methodology section of this manuscript. Each included functionality pays a significant role in re-creation of natural occupant movement. Lack of one or more functionality might generate a successful transition, but it might emerge due to the probabilistic chance. To check the significance of all ~~of~~ the functionalities, it was proposed to test all ~~of~~ the potential permutations of all ~~functionaries~~functionalities scenarios where each of them could have status as ON or OFF. This will include all functionalities ~~besides~~except EED. It does not influence the success of the pathway generation, but it might slightly increase the number of steps (iteration) if the dilemma is met. Therefore, it is a supplementary functionality that does not influence the success of the movement simulations. Each included functionality in the validation process can be implemented to the code as with status on or off. If FLD functionary is turn off, the agent has no information about the layout. It only has access to the initial and endpoint. Therefore, it will directly aim towards the endpoint of transition without concern of the surrounding geometry the

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obstacles. The rest of the functionalities (CVD, CAD, SDS) are considered as a status OFF when instead of using its discovered properties, its parameter is selected by random.

Consequently, CVD and CAD use the range of its distributions but do not use ~~the~~it for step selection. Instead, the variable is selected randomly. If SDS functionality ~~if it~~ is OFF, the agent chooses ~~by the random~~randomly one of potential steps.

In this validation procedure, ~~it will be~~there are sixteen different functionality scenarios. Previous studies have shown that typical daily transitions in a residential building are lasting for around 6000 seconds per day [47]. Each ~~functionality scenarios was~~transition typically lasts for approximately 5 to 10 seconds. It is approximated that occupants are committing about 1000 transitions daily. To check how the developed model is capable of simulating one whole day, validation simulations were tested ~~a thousand~~1000 times. Each test was evaluated ~~thru~~through the selected score variables. The baseline functionality scenario is the one where each functionality was set on a status OFF. Used layout for the validation ~~with~~and its results are shown in ~~figure~~Figure 6

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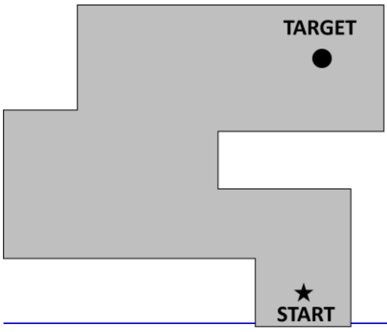

	Status of Functionalities				Validation Variables		
Case	CVD	CAD	SDS	FLD	Reaching the target	Too many steps	Leaving the layout
1	ON	ON	ON	ON	949	0	51
2	ON	ON	ON	OFF	0	573	427
3	ON	ON	OFF	ON	0	0	1000
4	ON	OFF	ON	ON	844	0	156
5	OFF	ON	ON	ON	928	0	72
6	ON	ON	OFF	OFF	0	0	1000
7	ON	OFF	ON	OFF	0	1000	0
8	OFF	ON	ON	OFF	0	1000	0
9	OFF	ON	OFF	ON	0	0	1000
10	OFF	OFF	ON	ON	773	0	227
11	ON	OFF	OFF	ON	0	0	1000
12	ON	OFF	OFF	OFF	0	0	1000
13	OFF	ON	OFF	OFF	0	0	1000
14	OFF	OFF	ON	OFF	0	1000	0
15	OFF	OFF	OFF	ON	0	0	1000
16	OFF	OFF	OFF	OFF	0	0	1000

Figure 6. Validation geometry with model functionalities validation results.

~~5. RESULTS~~

5. Simulator sample results

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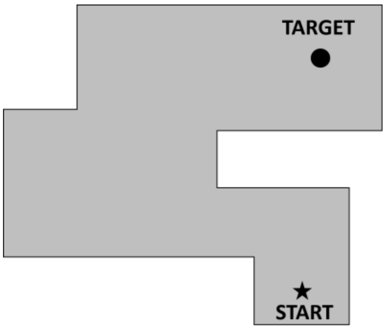

	Status of Functionalities				Validation Variables		
Case	CVD	CAD	SDS	FLD	Reaching the target	Too many steps	Leaving the layout
1	ON	ON	ON	ON	949	0	51
2	ON	ON	ON	OFF	0	573	427
3	ON	ON	OFF	ON	0	0	1000
4	ON	OFF	ON	ON	844	0	156
5	OFF	ON	ON	ON	928	0	72
6	ON	ON	OFF	OFF	0	0	1000
7	ON	OFF	ON	OFF	0	1000	0
8	OFF	ON	ON	OFF	0	1000	0
9	OFF	ON	OFF	ON	0	0	1000
10	OFF	OFF	ON	ON	773	0	227
11	ON	OFF	OFF	ON	0	0	1000
12	ON	OFF	OFF	OFF	0	0	1000
13	OFF	ON	OFF	OFF	0	0	1000
14	OFF	OFF	ON	OFF	0	1000	0
15	OFF	OFF	OFF	ON	0	0	1000
16	OFF	OFF	OFF	OFF	0	0	1000

To investigate abilities of the developed movement simulator, two type of tests were conducted, focusing respectively on general transition and ~~on~~ pathway repetition.

To simulate general transition, two zones were selected ~~to represent~~; a general transition inside an apartment and inside an office. Each simulation for this segment included the

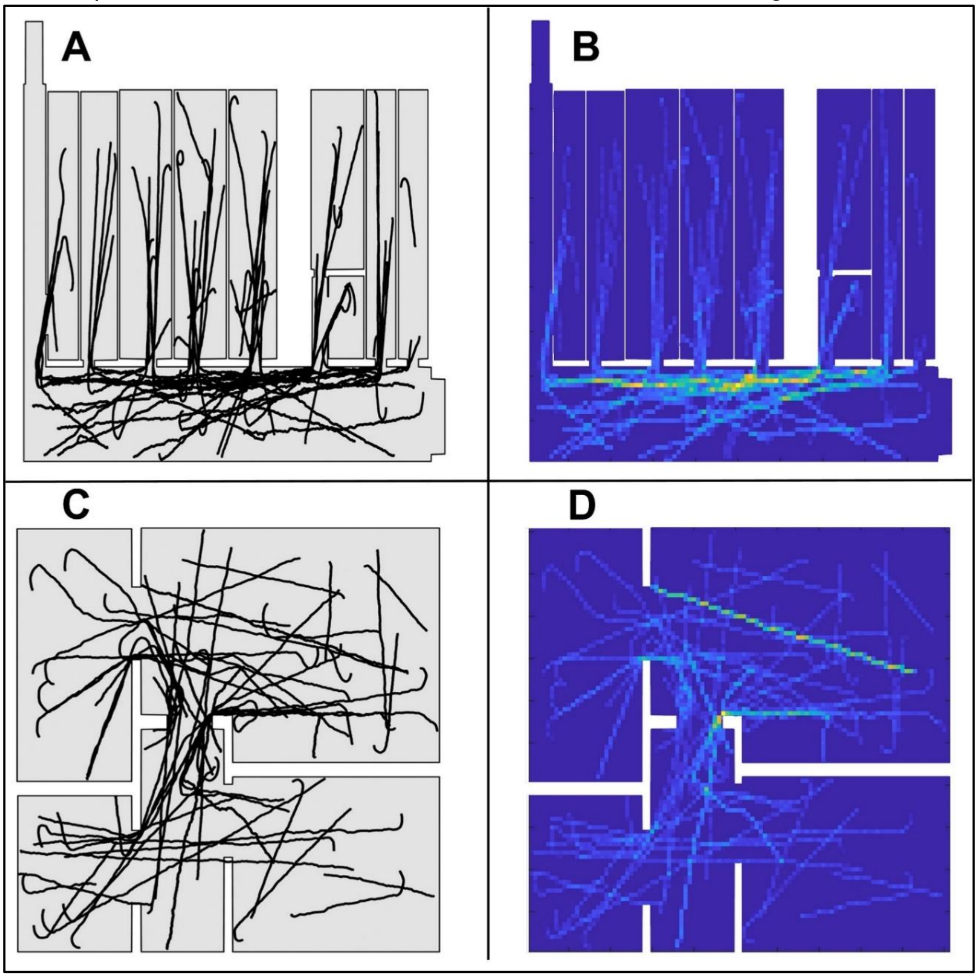

Figure 7. Simulation results for an office layout (A) and its heat map (B). Simulation results of a typical flat layout (C), and its heat map (D).

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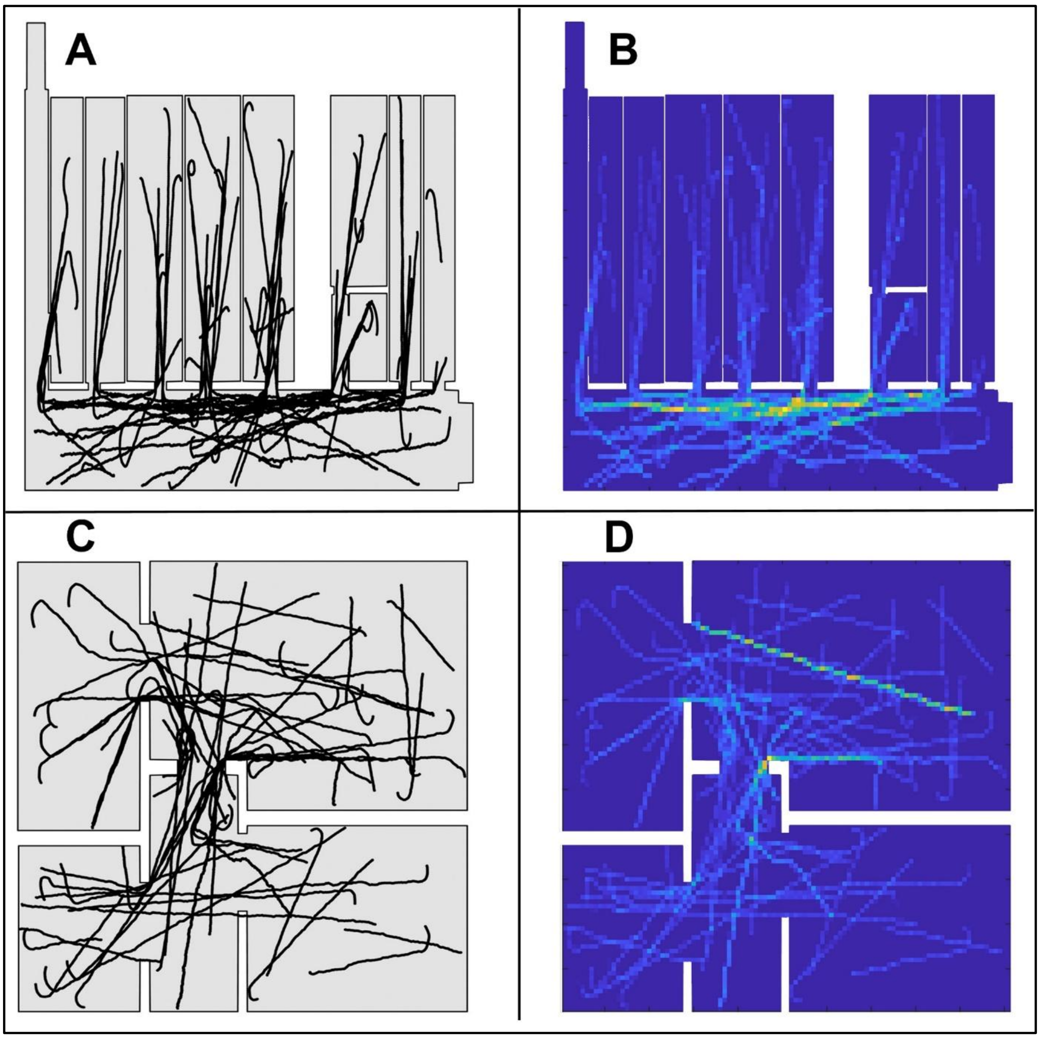
random positioning of the start and the end point. Each variation was simulated fifty times.



~~*Figure 7.Simulation results for an office layout (A) and its heat map (B). Simulation results of a typical flat layout (C), and its heat map (D).*~~

Transitions inside these layouts ~~were~~are displayed in ~~figure~~Figure 7 by the movement transition points and heat maps. Each heat map represents a cumulative value of an ~~agent presences~~Agent's presence in a particular space, operating on a fixed resolution. Higher number of generated pathways could make zone layout blur and it would be difficult to recognize single pathway. Each heat map was generated in a resolution of one hundred times one hundred, and dimensions of the whole layout are the boundaries of the heat map.

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To display the variability of the pathway repetitions, three simple layout scenarios were shown in ~~figure 6~~Figure 8. A simple straight pathway transition, an elbow connection, and a straight pathway separated by the wall parallel to the corridor length ~~were~~are shown. The result of these simulations ~~was~~is displayed similarly as previous simulation.

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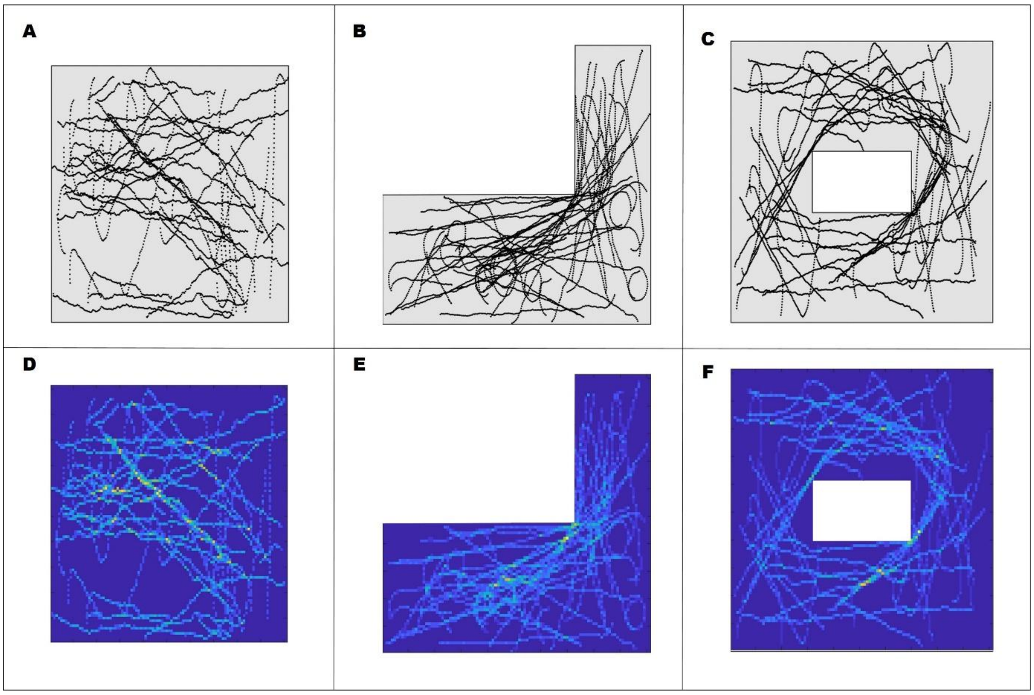

~~*Figure 8. Simulation results for different layouts.*~~

~~*Simple corridor (A), and its movement heat map (D). L-shaped corridor (B), and its movement heat map (E). Corridor separated by an obstacle (C), and its movement heat map (F).*~~

Each simulated pathway is represented by a gathering of the points displayed on a layout heatmap. Each path is described by the vector that holds spatial information of each taken step. For the result purpose, the initial localisation of the movement was selected randomly in space. As shown in ~~figure~~Figure 7 and Figure 8, no matter where the agent initialises its transition, it is capable of finishing its movement goal.

If this application were implemented in BPS software, then there would be an initial and end movement point in a similar location, of building/zone exit. The whole transitions are aimed to be simulated continuously until the agent leaves the investigated area. Information about the agent location can be used to draw an occupancy schedule, but it can also be implemented to investigate ~~high granular~~ occupant thermal comfort~~.~~ with high granularity. Ability to position the human body allows ~~calculating~~the calculation of a local radiant temperature. Additionally, the same step points can be used to probe data about local air thermal properties, if the used solver supported a multizonal simulation.

6. Discussion

The test of the developed movement simulator shows that it is capable of generating pathways that are not prescheduled. It operates on a simple coordinate system that does not require an extensive calculation power to operate. The general movement simulation process does not include a necessary preparation phase. This phase requires access to ~~the~~a polygon drawing that represents ~~a~~the floor layout. The process of vectorization operates on a raster picture. ~~That is why it might take some time until~~This makes the completion of preparation ~~is~~

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~~completed.~~a time-consuming process. The vectorization is ~~an~~a one-time process not induced in the general computational performance test. The necessary computation time for the vectorization relies on the complexity of the given area if it covers a large space, or it has numerous amounts of holes area inside. The same situation concerns the description of the coordinate system. Once it is calculated, it can be explored until there is no significant change inside the building layout. Additionally, numerous possible corridors influence the calculation time process. General simulation of the transitions of each case took approximately five minutes, without plotting transition pathways. It must be pointed out that each case was exposed to one thousand simulations, where each simulation had a mean value of three hundred steps, and each step was simulated in approximately 0.01 ~~seconds~~second. Such fast processing allows to assume that it is possible to simulate transitions of more than one occupant in a relatively short time. If such performance is maintained during the whole simulation procedure, simulation of the whole year of transitions can be done in twenty-four hours, with the assumption that each year an occupant spends 10% of its total time on a transition movement. Used computer hardware specification was described in the acknowledgement.

Tested layout scenarios were drawn as an orthogonal shape. A vectorization method would be able to handle the process of more diagonal shapes but not more opaque shapes. Any kind of rounding could be considered as a corner, formulating an advanced structure of a polygon at the same time. This problem could potentially be solved by simplifying the shape by fine resolution grain, or by the introduction of a round shape detection function that will immediately detect the existence of a rounded shape, and it will describe the shape with an arc-shaped vector.

Zone layout outlines are necessary to detect the corresponding points and to hold agents inside the layout. Their primary function is limited, but it can be extended. The whole zone can be multiplied and separated as a layer. Each layer can be responsible for different floor features such as the placement of the furniture, doors or electrical appliances. It can be done in the same way as it is organised in BIM software (e.g. Revit or Sketch Up). It can share similar modular architecture. Each included device must be described by the extensive metadata that hold information about device dimensions, localisation of coordinate points, and the list of activities it can be engaged in. An example of the simple scenario scene is displayed in ~~figure 7~~Figure 9. Each activity had different corresponding pathway colours. All the included actions were kept in a pre-scheduled sequence. In this simulation, the agent was instructed to start from the home office zone and to sit in front of the desk. After that it was instructed, to enter the kitchen (red path), pick up a meal from the refrigerator (blue path), cook the meal on the stove (magenta path) and finally eat the meal while using the table in the living room (cyan path). Once the meal was finished, the agent had to wash the dishes at the sink (black path) and go out of the flat (yellow path).

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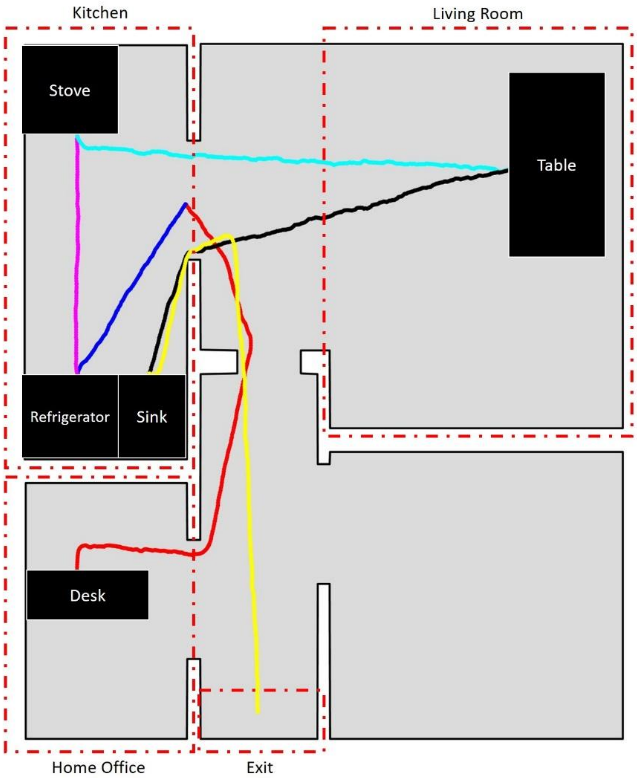

~~*Figure 9. Simulation results of the sequenced movement inside the selected layout.*~~

~~*Each taken pathway is coloured by the corresponding action.*~~

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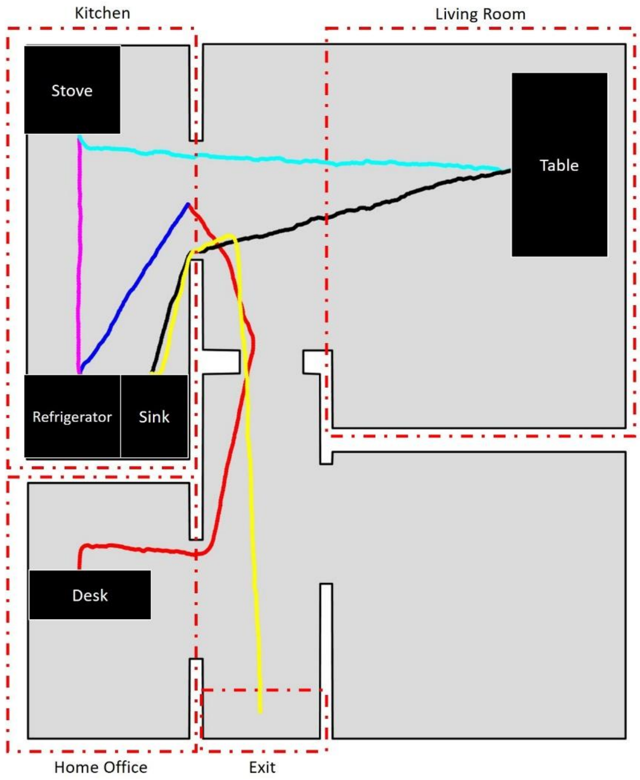

Figure 9. Simulation results of the sequenced movement inside the selected layout. Each taken pathway is coloured by the corresponding action.

Movement of the agent is represented by a singular point, but it can be extended to full body representation. Data collected via the depth registration technique allows for a formulation of the whole-body numerical representation. It can be transferred ~~into~~to the movement simulator as well. Projection of the body can be re-calculated by the defined number of points. Therefore, it is possible to generate numerous three-dimensional strings that represent points of the human body transiting inside the indoor space, which can be used to monitor how the agent is exploring and perceiving the given space. Information of the body turning and placement of the limbs can be used to sense the environment by using other numerical software such as IDA-ICE or ANSYS Fluent [11], [~~47~~48]. Data obtained from these external sources can be used to generate a feedback loop for an agent to react on given environmental conditions if such rules are applied.

7. Conclusions

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The current state of the ~~BOT-ABM~~building occupant transient agent-based model development can be considered to be a foundation of an artificial intelligent ~~OB~~occupant behaviour model, but further progress requires more research. The current state of the model allows formulating a series of next tasks for the development of a comprehensive agent-based model enabling human-centric building design.

The movement simulator that has been developed delivers a new dimension for building energy performance simulations. Use of this application allows simulating all occupant transitions inside the buildings. It includes actions related to adjustment of the comfort, opening the windows or adjustment of the setpoints on the thermostat. All these actions require movement of the occupants to be conducted. As~~ it was~~ shown in the Results section, the tool can deliver the functionality of formulating a procedural generation of pathways taken by building occupants. It does not require an advanced artificial setup of the pathways, which can be considered a time-consuming activity. It allows to put the focus on the scheduling of the activity or programming the potential reactions of human behaviour. Therefore, that task can be introduced to a broader audience, not only to building design practitioners or ~~energy-oriented scientists~~scientist related to the field, but also to social scientists, behaviourists and psychologists. Use of this technique allows for an extraction of data about the position of the individual body. This information ~~will~~can also contribute to ~~OB~~occupant behaviour thermal comfort models. Ability to probe data about indoor air states from numerical simulation allows for the introduction of the new numerical solver that reacts on a particular "sensed" condition. In consequence, it will influence simulated building energy performance by adjusting the indoor environment to its preferences.

The main functionality is simulated by the simple solver, which leaves significant space for the addition of potential modulators. The source of those triggers can be obtained from other future implemented modules of the building occupant transient agent-based model. Execution of the signal modulation inside the solver can be done by providing a set of additional variables in the decisions of the agent making the step. For example, while selecting the pathway, the main driver is pathways distances between the start and the end point. However, it is possible to influence the pathway selection by other parameters that could originate from other modules, e.g. possibility to fulfil other tasks on the fly, or preferable thermal conditions of a different pathway.

As shown in ~~figure~~Figure 9, the agent can simulate pre-scheduled activities being "aware" of the placement of the features. This assumes that agent is familiar with the used space. Hence, it does not require permanent space recognition systems, such as Simultaneous localisation and mapping ~~(SLAM) [48], ~~[49], [50]. Therefore, simulated occupants, i.e. agents behave, such as typical ~~users~~occupants of that building do. Implementation of the "first-time use occupants" module can be conducted in a similar simulation environment, but it requires a different computational approach.

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Floor layouts used in the displayed simulations (~~fig~~Figure 7, ~~fig~~Figure 9) were quite large, with a relatively advanced connection grid. In the future, the indoor layout connection grid should be decentralised. Use of one large connection grid should be avoided. Otherwise, it will generate an unnecessarily complex connection matrix to simulate. Each room can be separated by the doors, which can be considered a separator and coordinate point. Implantation of this feature will decentralise the connection graph, which will significantly reduce the complexity of the connection matrix. Simplification of the connection matrix will automatically accelerate the computation time. Additionally, if during a simulation, more than one agent was included, it would be necessary to constantly~~ to~~ update the connection matrix by moving the position of supportive corner points from the agent. Operation in ~~an~~a one-connection matrix that would require such constant refreshment would generate unnecessary use of computational power.

The introduced foundation of the agent-based model can follow a given instruction of the activities/actions. No matter how complicated scenario is generated, the agent will be able to follow its instruction. Development of the tool that allows the formulation of the action instruction is not yet available. This feature will be addressed in the ~~following~~future research. Additionally, it is recommended to describe actions in a way that allows for a certain degree of freedom of a behavioural pattern's digital representation. Each task should be described by the time that it should last, parameters that it might influence, and input arguments that might ~~module~~modulate its action. With such a comprehensive description, the agent would interact with the given environment more autonomously. Introduction of this parameters should be followed by a description of personal profiles of the occupants. Ability to describe and generate~~ the~~ various profiles of occupants would allow testing their reactions to the given environment during the design. Occupant profiling should include parameters that hold a certain level of individualism, such as thermal comfort or hunger.

Access to all the mentioned functionalities can increase the accuracy of general building performance simulation. The implication of the presented simulation methodology can contribute to a better understanding of building ~~users~~occupants. A better understanding of occupant needs might contribute to development of the new, human-centric rules for building design and control. It can be used to identify limitation of already existing buildings and propose a solution that might optimise building energy use and increase the general well-being of occupants. The present movement simulation method would add a missing piece that links the dynamic behaviour of occupants with building design and simulation software.

Further extension of the present movement simulation tool will eventually grant the ability to develop a "digital twin" of the building. ~~Were~~Where each object included inside real-building, has its digital representation in a software. As already recognised, humans play a significant role in building energy use. Therefore, their presence and activity must be included in every simulation of building performance.

Ability to generate high-resolution sampling of the movement patterns can benefit numerous applications. It can allow simulated occupants to probe information about the micro-environment ~~souring them and~~surrounding them. In the same time it can introduce a threshold-based feedback control of the building control system. Not only does it allow to investigate the implications of the proposed ~~HVAC~~heat, ventilation and air conditioning system, but it can also be used to benchmark building sustainability and resilient. Such a solution enables testing the security of the building and system design regarding the handling of various weather conditions. Oncoming global warming correlates with frequency appearance of hazardous weathers conditions such as heatwave. With the proposed application, it is possible to simulate dangerous weather conditions and check what is expected thermal stress that the human body will be exposed. Access to such information might influence future designed routines, where potential misconduct might directly affect occupant's health security.

The idea of this model is to simulate natural occupants' indoor transitions. The current stage of the model allows simulating transition of the occupant represented as one point in the plane, which is the current limitation of the model. Even if the position of the skeleton model will be described by a three-dimensional humanoid, it is not possible to re-create all of the natural limp pendular movements while transiting. Additionally, each interaction with an appliance or furniture in a room has no representation in motion-captured limb transitions. Skeleton model stands stiff in front of its target. The current model assumes a particular amount of time that occupant is interacting with its destination place. If both of this issue were addressed, it would open a possibility to simulate an occupant activity rate, by introducing a physical property to each occupant limb. Future research should focus on resolving this issue and delivering a promising tool for building performance simulation.

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8. Acknowledgements

The data collection and storage method applied do not allow identifying the participants of the study. Therefore, this study does not require certification by an ethics board. The authors declare that they have no conflict of interest. For this type of study, formal consent was verbally delivered by the participants of the study. The authors do not endorse any specific brand or device developer. The study has not been sponsored or influenced in any other manner by private companies.

The computer setting for the measurement procedure was as follows: Intel® Core™ i7-4785T with a CPU of 2.20 GHz: 16 GB DDR3 RAM; Intel HD Graphics 4600. Using a different setting of hardware for the measurement purpose may influence the sampling time. This publication does not seek to promote any specific product or brand.

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***Highlights (for review)**

- Unscheduled simulation of the occupant behaviour in buildings
- Simulation of individual occupant behaviour by the agent-based modelling
- Support for the personalising of the designed building space
- Possibility to investigate individuals comfort during building design phase

BUILDING OCCUPANT TRANSIENT AGENT-BASED MODEL - Movement Module

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Abstract

Simulation of occupant behaviour (OB) in buildings is a challenging task. Available software uses a broad spectrum of tools that try to reproduce the patterns of human activity. From building energy perspective, the main emphasis in research has been focused on discovering behaviour directly related to energy. In recent years, more attention has been given to simulating occupant actions that are indirectly influencing building energy use. In most of the cases, this is achieved with the use of agent-based modelling. which allows describing occupant actions on a room level. According to the existing methodologies review, it is a proper step, but to include occupant behaviour in energy simulations, spatial and temporal resolution of the occupant behaviour model must be improved. Addressing this issue requires the development of a comprehensive model supported by numerous modules that would cover various significant occupant actions. This paper focuses on the development of the high-resolution, data-driven movement engine of occupants. It is one of the fundamental modules necessary to simulate occupant behaviour with high granularity. Once the model is developed within its essential functionalities, it will deliver a bottom-up model capable of testing various energy use strategies. It will allow for testing different heat, ventilation and air conditioning solutions and the responses provided by simulated occupants. The data used to develop this module was obtained thru in-situ measurements, with the use of depth registration. Information obtained from experiments is similar to previous research, but it also extends the investigation scope with an additional transition-based variable.

1. Introduction

1.1 Background

Building performance simulation is a common tool used in the design phase of a building. These tools make it possible to investigate several scenarios for the design conditions and select the one best suited to the given situation. The information provided is with the results of these simulations makes it possible to optimise the overall energy-use of the planned building. The energy performance of a building is influenced by several factors, such as construction faults, setup of the Building Management Systems (BMS) etc. To achieve an accurate design target with the simulation tools, it is necessary to take all the influencing factors into account. Even after accounting for all these factors, the energy performance eventually relies on the building occupants. A study conducted by Turner [1] shows that only 30% of the analysed buildings have similar operational and simulated energy use. Based on previously conducted research [1], such a mismatch between simulation and commissioning results might be caused by oversimplifying the factors like: occupant behaviour, construction quality, weather profiles etc.

The significance of the behaviour of building occupants on energy use has already been acknowledged. The description and foundation of current indoor environmental standards (ASHRAE 55 [2]) was made half a century ago by Fanger [3]. Since this milestone, the work on this subject continues to this day. The recently finished IEA EBC Annex 66 delivered a significant contribution to this field by organising knowledge that already exists and provided organisation and instruction for the next steps of development [4], [5]. The final report of Annex 66 [5] also pointed out that newly developed models should aim towards the occupant description on an individualistic level. Additionally, such models should be able to simulate various occupant indoor activities. Based on existing literature, occupant behaviour (OB) is usually represented as a stochastic process [6]. It means that each conducted action is assumed to have its reason and can be explained, although the accumulation of similar, registered activity can formulate particular distribution. The same action cannot be conducted under the same conditions: that is why its repetition might generate certain variations in performance or instruction in reaching a similar goal. The repetition might generate a sensation of the randomness of the observed action, but it is not the operational driver of the action. Direct OB cannot be considered stochastic due to the deterministic nature of the actions of the occupants. That is why the actions of building occupants should be analysed holistically to highlight the ways of reaching a similar target, which can later be extracted into the description (recipe) of achieving the goal. The only exception in forming the spectrum of possible behaviours is irregular behaviour [7].

1.2 Challenges in OB modelling

Indoor OB is a complex phenomenon. Therefore, development of a functional simulator is an iterative process, and it requires access to various data sources. Conducted study by Yan et al. [8] reviews, segregates and evaluates performance of OB models. In this study, many existing models are considered. Evaluation of the models took into the account three resolution criteria (temporal, spatial and occupational). Some of OB models that were considered were models already implemented in BPS software like Energy Plus [9], [10], IDA-ICE [11], [12] or De-ST [13], [14]. C. Wang et al. [13] application was not taken into account in this review, but its contribution was already implemented in a DeST software while performing the review. One of the most accurate models has reached a temporal resolution of ten minutes and a spatial resolution that allows simulating the zone occupancy state [9]. Description of the zone occupancy state can be considered as a good enough, but as pointed out by Yan et al. [8], it does not allow for re-creation of the behaviour of the individual occupant. Newly developed models need to aim towards higher resolutions of occupant description and better robustness.

Similar conclusions can be found in the work of Dong et al. [15]. As that study highlights, no solutions promote integrity or a broader framework for a spectrum of applications. Most of the models developed in this field are focused on presence of occupants, counting of occupancy, operation of windows, operation of blinds, operation of indoor lights, HVAC sizing and thermal comfort, crowd and security simulations, and design of building installations [15]. Usually, each model focused on one particular phenomenon related to OB. Proposed by Gaetani et al., the method of segregation of the models is one of the plausible steps towards the development of a communication platform [16]. Categorisation of the models in such a fashion proves that there are no universal models and the topic of energy-related OB in the building is complex phenomena.

1.3 Use of ABMs for OB

Based on provided evaluations, the new OB model requires changes in the observation of occupant actions in buildings. It is assumed that an extension of the observed spectrum of OB by new measurement techniques can improve the quality of the model. Following the conclusion delivered by Yan et.al. [8] and Dong et al. [15], the newly developed model has to operate at the same time duration, as actions conducted by occupants might last. The same principle must follow the spatial localisation of their activity. The result of such measurement might produce additional noise to the data, but it will allow capturing reasoning for the actions that occupants conducted. Therefore, the occupants must be identified correctly in the BMS system and properly described, and the resolution of the data collection should allow for capturing the smallest significant event [16]. If such requirements are fulfilled, it is possible to process the data that have been gathered without losing any context from each registered activity and to gain in-depth knowledge of the observed subject. The main challenge related to this approach is its significant difference between operational temporal resolutions. Occupants conduct their actions in a temporal resolution of a second (or even less), where a noticeable reaction on a condition may last many minutes or more. The difficulty is simulation scaling. The cumulative sum of the actions of the occupant cannot be considered a significant approximation due to the dynamic nature of the behaviour of the occupant. Observed reactions to the given indoor conditions might be dependent on numerous factors such as thermal conditions, acoustic conditions, purpose of the occupation, and many more [17]. Therefore, activity sampling for the building occupant with the frequency of a second can be considered a sufficient operational resolution. Such resolution extension would address conclusion delivered by Yan et.al. [8] and Dong et al. [15]. High-resolution sampling should allow capturing each important event, from the perspective of the building occupants. Discretisation at that level leaves relatively small room for any potential misinterpretation. However, such hardware application requires delivery of the probed data in the least invasive way. Meeting such specifications can be considered a challenging task. Fortunately, such challenges were addressed in past research. Currently, it is possible to fulfil this requirement with inexpensive gears [18], [19], [20], [21].

Fulfilment of the requirements for the new OB model can be achieved with the use of agent-based modelling. It is a promising technique that is capable of re-creation of occupant behaviour that meets the three resolution criteria. This modelling technique allows design of an artificial being (agent) that can operate in any given environment. The agent reacts to the given conditions, based on given targets and specifications. Additionally, the agent can deliver feedback for any condition, even those that are not pre-scheduled. The agent follows instructions from the delivered set of rules. Rules could be considered to be a habit or "personal" preference [22]. This modelling technique allows for introduction of the modular OB model where each module is responsible for one particular OB-related phenomena. This approach allows for description of the OB through the perspective of the occupant. Currently, there are agent-based models focussing on human reactions that have origins in a building occupant [23], [24], [25], but its granularity does not catch up with future targets proposed by Yan [8] and Dong [15]. The applications that are closest related to human behaviour simulations are simulators that focus on fire escape [26], [27], [28], evacuation pathway testing [29], [30], strategic and aid support [31], crowd management [32], [33] or pedestrian movement [34]. None of mentioned models put extensive emphasis on the development of a sophisticated description of the distinct person. The most advanced agent-based models have functionalities such as agent age, sex, speed, maximum acceleration, body size, health and strength. Those functionalities are implemented in fire escape simulations [26]. With these parameters, it is possible to simulate complex fire escape scenarios with various placements of the fire origin. These methods are especially useful to test scenarios that aim to minimise causalities among exposed populations. This target can be obtained by different placement of sprinkler system, proper control of the smoke ventilation and crowd discharge columns. Similarly, other applications mentioned above were designed to investigate specific phenomena. It is noted that most ABM simulators of the OB are polarised into one of the two categories in terms of the temporal resolution. Most of the energy OB ABMs are aiming towards hourly simulations to capture the annual performance of the building. Another is more like an event-based simulation (like evacuation). Simulation timeframe does not last for a prolongated time, but its temporal resolution is close to capturing sudden occupant reactions.

2. Aim

Development of holistic OB models is already a well-known task in the research community [35], [36], [37], [38], [39], [40]. Nevertheless, a merge between precise (whole simulations that last for one particular event, with a high temporal and spatial resolution) and existing hourly models was not found in the literature. To connect those two approaches, it is necessary to divide the whole model into distinct modules due to the nature of its complexity. Each module has to communicate with other subparts and has to be reliable. Therefore, the development procedure has to be taken care of with extra caution and attention to details.

Based on existing literature it is necessary to develop a OB simulator tool that is capable of operating on high spatial and temporal resolution that can also perform annual simulations. Its application should allow for a fit-for-purpose approach of OB simulations. With the proper tool, it would be possible to investigate various occupancy scenarios and test whether there is space for potential optimisation of the building energy use. To address these issues, it is necessary to create a tool capable of conducting simulations that re-assemble the patterns of normal building usage. Such a tool must operate in an energy-cyber-physical system that might potentially be used during the design and operation phase of a building. The suggested tool should allow for a human-centric design of the building, where the existence of the occupants is not marginalised or oversimplified. The framework of such a model was described by Dziedzic et al. [41]. Progress towards such a goal must be initialised with a description of the basic functionality of the occupant. Each functionality will be referred to as a module.

The description of the actions conducted inside the room/zone by the occupants requires proper localisation. Information about the localisation state of the occupant might be used to describe the thermal preferences and actions that the person is engaged with. Thus, the initialisation point of the new occupant behaviour model should focus on the development of a solver capable of simulating movement indoors. This paper aims towards the development of the movement solver by analysing collected data through depth registration. The developed solver is a foundation for the new agent-based model. The primary purpose of this solver was a simulation of individual transitions inside a known building layout. It is assumed that the layout of the simulated zone is known, and the agent also recognizes starting and finishing points. The agent must generate pathways similar to the natural transition of the occupant. Therefore, the created pathway will not be optimal, nor the shortest. Such algorithms are already existing.

3. Methods

3.1 Collection and access to the data

Development of the movement simulator needs to rely on data obtained during the *in-situ* observation of the natural transitions inside the building. With the use of depth registration camera, it is possible to obtain this information. This technique allows observation of a surface in a space using an infrared projector and camera that allow monitoring a reflection of the projected beam. Collected information can be transferred into the raster map, where separate pixels hold information about the distance of the monitored surface. A static picture can be treated as a background. Any obstacle that crosses the monitored area will be distinguished from the background and treated as a dynamic object. Cover range and accuracy of this camera are directly related to the image amplifier that has been installed in camera. There are many available devices on the market capable of conducting such measurements. In terms of application readiness, one of the most popular cameras is the Microsoft Kinect v 2.0 for Windows [42]. Due to these reasons, this device was selected to be used in experiments. Access to the data and its applications was well described by Dziedzic et al. [20]. In short, the selected device transfers a humanoid-like shape into a built-in skeleton model (SM). The SM is a twenty-five-joint model, where each joint match up with a designated place on a humanoid body. For example, if the joint should be located at the base of the spine, the SM will try to estimate its position based on an observed shape. Each joint is described by four variables, three-dimensional information of the distance from the device centre point, and global clock information. Collection of the information from all joints can be used to formulate principles of the movement simulator.

Data collected through depth registration requires some amount of post-processing. With proper software tuning, it is possible to keep the data collection procedure in an infinite loop. Due to the hardware limitations, each procedure might collect a number of “frames” until the computer buffer memory runs out of space. To avoid this situation, each package of collected frames is transferred to the hard drive, which requires a temporary pause in the depth data acquisition. Consequently, if occupant was performing a transition while data was transferred to hard drive, few frames of this transition might be unregistered. To bypass this condition, double registration of the same scenario is required. Such a procedure minimizes the possibility of missing any potential activity. The number of collected frames is limited by the hardware calculation capabilities that are used. Data used during the development of the movement simulator module were accessed from the compilation of previously conducted research. Each participant in the experiments was adequately informed about the quality and quantity of collected information. All the participants gave their consent to collect and process data obtained with the use of the depth-registration camera. Therefore, the research that was conducted did not cross any ethical boundaries.

3.2 Data Processing

Collected information about occupant activities must be post-processed in two steps: projection surface recalculation and pathway clustering. The device used in the experiment defines a local coordinate system. The position of the device and its angular position influence the data collection process directly. Fortunately, it is a repetitive error that can be eliminated by a transformation matrix that straightens the observation angle. Information about the transformation surface can be obtained via analysis of selected joint SMs. Use of joints that are not contributing significantly to the pendular movement of the human body is recommended, due to stability of the readings. For example, any of the joints that describe the spine. Analysis of this spot allows a description of the operational surface, where all measurements must be re-calculated to estimate the height-axis transformation vector. Points from the foot joints must be projected on an operational surface, and an average distance must be set. Once the data are calibrated to represent movement on a straight floor surface, it is possible to proceed with the next post-processing step.

A set of the whole number of points acquired during a measurement procedure can be connected in a formulation of the single pathway. To distinguish each pathway, it is necessary to apply a classification technique. Due to the significant amount of the recoded movement, it is necessary to use an unsupervised segregation technique. Additionally, the deployed processing methodology must be capable of connecting the missing pieces of movement records that occur during the temporary pause mentioned above. To fulfil all the given restrictions, a modified density-based scanning method (DBSCAN) was deployed. The principles of formulation of DBSCAN were introduced already in the 1970s [43], but back at that time, it did not attract too much attention. In recent years, this method has gained increasing applicability due to the ability to use it in the unsupervised cluster spatial data series. The method mentioned operates on two operators (alpha and epsilon) that must be set according to the data granularity. Operator alpha describes a range of the investigation spectrum of the point that is currently being considered. Operator epsilon controls how many points inside the alpha range must be included to consider such data set as a cluster. This method is efficient in detection of complex shapes and denoised data sets. According to this DBSCAN description, this method does not require definition of observed clusters. Therefore, there is no need to keep track of how many paths this clustering method must detect. To correctly detect classification of the given cluster with the use of this data type, it is necessary to introduce an additional dimension where temporal distance plays an important role. Otherwise, most of the collected data points will belong to the same cluster due to the spatial overlay. Introduction of the time parameter as an alpha variable block under classification enables data connection due to the temporal data acquisition.

3.3 Development of the movement solver

Segregated data sets were analysed to capture movement statistics. In this step, each detected path was processed separately. Each point in the recorded pathway was considered, except for the last step point. Statistical analysis included parameters such as movement speed distribution, and movement angularity distribution. Observation of the movement speed was done by direct calculation of the distance between the present step and following step divided by the amount of time between these two points. The second parameter was the movement angularity distribution. If each point can be considered a local Cartesian coordinate system, each next point formulates a corner with an x-axis, which has its angle value. The difference in the angle value between the present and previous step can be considered an angular movement fluctuation. These values aggregated in summary of the whole movement are considered a movement angularity distribution, which are processed later. The results of all investigated distributions are shown in Figure 1.

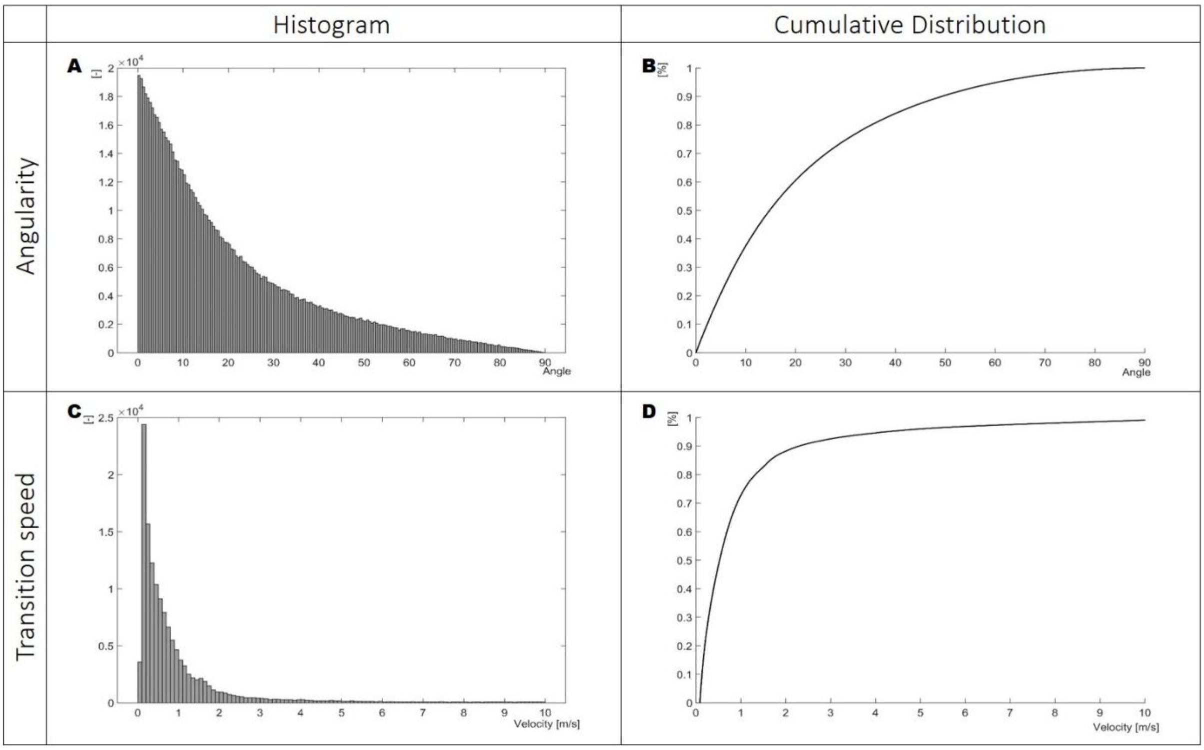


Figure 1. Movement and Angular distribution of used data sets. Cumulative Angular Distribution (CAD) and Cumulative Velocity Distribution (CVA)

As shown in Figure 1A and Figure 1C, both distributions show a particular pattern of movement of the occupants. Most of the observed transitions of most of the movements are conducted at a speed between 0,5 - 2 metres per second. In terms of the angular distribution, there were no transitions that required a larger angular difference than 45° in one step. Analysis of the step progression did not show any significant proof that there is a pattern, where step speed accelerates in a particular phase of transition. Both variables were tested in terms of the correlation between each other. Surprisingly there is no correlation (correlation value of 0.015) between step velocity and angularity. It is a counter-intuitive statement, but there are no proofs to claim differently. Both speed and general angular distributions are formulated into cumulative distribution function where the order of sampling is dependent on the lowest to the highest value. Once both distributions are transferred into a cumulative distribution, both newly formulated curves are described by the function using polynomial regression. Obtained distribution function formulas are used as a basis for the simulator development. Using the random function as a solver, it is possible to obtain access to the variable values from both cumulative distribution functions (speed and angular distribution), allowing for a simulation of the transition steps. Additionally, the obtained cumulative distribution of movement speed matches with the previously generated distribution from conducted research that used GPS data [44]. As an additional novelty, it must be pointed out that with use of the depth registration camera it was possible to obtain a cumulative angularity distribution, that was impossible to generate with previously used measurement techniques due to is small spatial accuracy.

To simulate the movement of an agent, it is necessary to give it a selected target for a transition towards which it can aim. To do so, the room coordinate system is developed, and its development will be explored in the following text. Each time when a new step is updated, the agent moves following the vector generated in a previous step. Each time the agent is re-solving a selection of the step parameters, it updates its distance and angular difference from the turn of the previous vector. The side of the angle differential is selected by estimation of the future position from both sides of the previously followed vector. Both points are tested in terms of the distance from the aimed target. The shorter distance from both of the projections selects which is the following step position. Solving the dilemma at equal distances will be addressed in the following text. The sequence of pathway selection is illustrated in Figure 2.

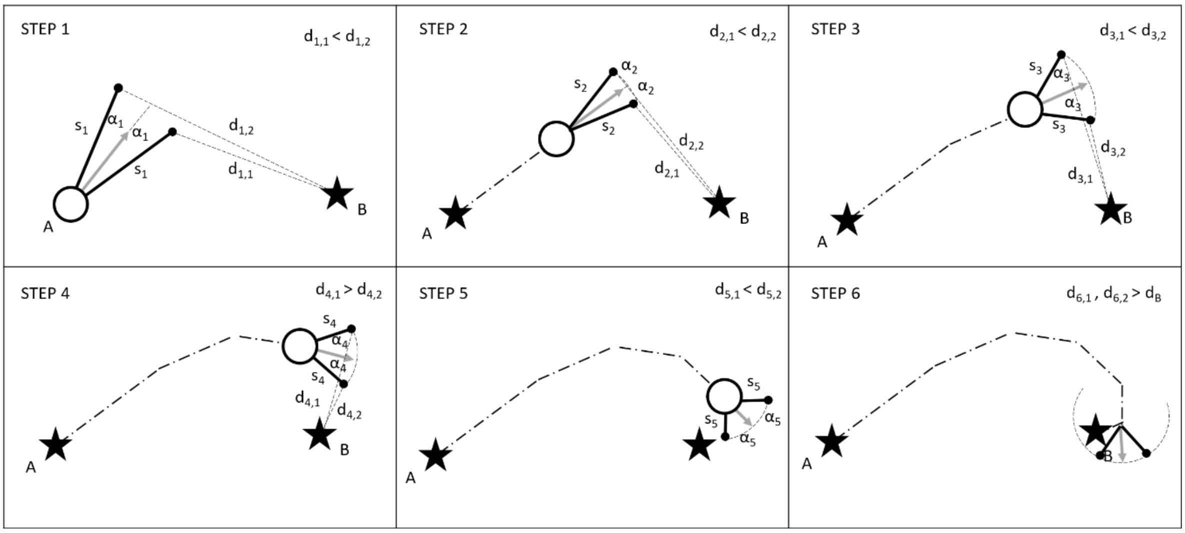


Figure 2.Illustration of the step sequence of the movement. Star A - starting position; Star B - end Position; s_i - simulated following step distance; α_i - simulated following step angle; d_i - distance from the following positions to the end goal; grey arrow - starting/previous agent turn; black end-rounded line - simulated position in the next step; dash dot line - pathway; white circle with black borders - agent

3.4 Floor layout and coordinate detection

The solver that has been developed can simulate any given step re-creating the natural distribution of steps taken. To transform the designed solver to a form applicable for BPS, a definition of operational space is required. To do so, it is necessary to develop a grid of connection that represents a floor layout structure, that is used for this simulation. Obtaining the connection grid is generated automatically for any given investigated space. The source data for investigated space originates from a vector polygon drawing or a raster picture. If the layout is defined using the vector polygon, there is no need to prepare the layout for further processing. If the delivered information about the floor layout is available only in a raster picture, it requires further pre-processing. The raster picture of the floor layout is transferred to its binary representation, where the space representing floor layout has a value equal to one, and the rest of the features (such as walls) have a value of zero. The first step towards vectorization is the detection of the corners and outline of the given layout. Outline and corners are located from both the inner and outer sides of the layout, allowing for simplified further processing. If the emphasis on outline detection was put in one of the sides, it could potentially generate a formulation of pixel "stairs" that would complicate further calculations. Side outline points located on the inner side have surrounding five positive pixels. On the outer outline, side points have a sum of three surrounding pixel. Correspondingly, for the corners, the inner outline is four, and the outer outline is one. Detection of the whole set of the pixels on edges on the floor layout allows for a formulation of the layout pixel set, that are analysed by DBSCAN to classify all the selected pixels. If the clustering technique detects only one cluster, it means that there are no more non-connected outlines, which implies that this specific layout has no "holes" inside the layout. If there are more clusters detected, the vectorization process requires one additional following step. Access to the vector description is essential for the general reduction of the processing time of the movement simulator. Operation on a vector requires significantly less computational time than the constant recalculation of the high-resolution raster picture. Therefore, pre-processing of the raster type input is addressed properly.

Each outline cluster detected is described by the continuous sequence of points representing corners in a selected order (clockwise or counter clockwise). The last points are the same as the first, to close the entire loop. Because each corner was represented by two points during the detection process, from each pair of the mutual corner points, only one was used in the following process. Each corner point that has a value of one was used during the outline segregation procedure. The formulated outline sequence is directly transformed into the vector polygon. To check the quality of the vectorisation procedure each pixel that represents layout, is catalogued by its localisation value. If the sum value of all the points included inside the polygon, is equal the total amount of catalogued points, it means that the polygon was detected correctly. If it is smaller, it means that there are holes inside the formulated polygon area, and its localisation has to be re-addressed. The same process of corner sequencing continues for each detected cluster. If the detected cluster, translated into polygon has a total amount of catalogued points equal zero, it is a definite "hole". Each detected "hole" is subtracted from the main polygon area by the Boolean operation. This process continues until the main polygon is formulated properly and passes the quality check test. This process assumes processing of one zone/room that does not allow for a formulation of the multiple "only positive" zones. If there are multiple starting clusters, the main starting cluster is selected by the largest initial area, before Boolean reduction of the space size.

Once the vector description is available, it is necessary to extract information about all the vector corners to initialize the process for automatic detection of the coordinate system. Each corner is being paired with others included in the set to position midpoints between connections that are capable of "seeing" each other without obstacles. The probing line is a set of artificially generated points on a line connecting two corner points, where the points are generated by the number of even divisions of the connection line. This probing line is responsible for detecting the obstacles. If there is any point from the probing line that is not included inside the polygon area, it means that this pair of corners is not visible by each other. Therefore, the midpoint is not formulated between these corners. This process of detection is illustrated in Figure 3.

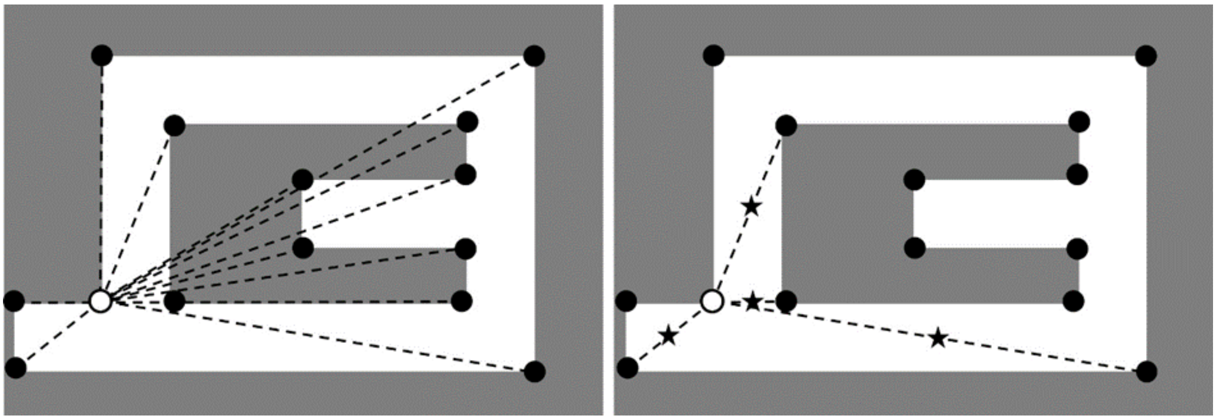


Figure 3. Examples of coordinate point's detection. Grey area - walls, obstacles, non-transparent features; white area - floor area; white circle - investigated corner; black circle - all the other corners; dashed line - connection to the different corners; star - detected coordinate points

All the midpoints that are included on the edge of the polygon are not included in a further step. Each midpoint that is included in the main set obtains its individual fixed number.

The set of all midpoints has been tested according to the same principle as in the previous step. With the use of the probing line, midpoints are investigated in terms of the visibility to each other. Each visible midpoint highlights its visibility by marking it in a connection matrix (CM) for the other. This matrix is responsible for the formulation of the relationship between midpoints. It has a size of n*n, where n is the number of midpoints included in this analysis step. Each time there is a visible connection between two points, CM updates its status by giving value one to the cell that is represented by the row/column and column/row for both points. CM is symmetrical. Once the whole set of midpoints is tested in terms of their visibility to each other, CM is tested in terms of its potential for simplification. Each row that has a unique set of other connections is kept for the final version of the CM. If there is a row of connections that has the same set of connections but fewer connections than its comparison with other points, it is removed from the final version of CM. The result of this removal is that the amount of points is reduced to the necessary minimum. All the points included in the final CM will be used as main coordinates for the movement of the agent inside the selected layout.

3.5 Transition simulation

Simulation of the movement requires the definition of the start and the end points. For the purposes of the test, start (A) and end (B) points are being generated randomly inside the floor layout. Before the transition process can be initialized, the solver must select a set of CM to generate a pathway connection. The pathway between A and B must be established with the use of the coordinates from the final CM. The driving force for optimization of the pathway will currently be a distance. The root optimization will be done with the Dijkstra's shortest path routing algorithm [45]. This method delivers the shortest pathway based on a wage connection system. The generated matrix of connection will be re-calculated into the distance connection matrix, where each cell represents the distance between corresponding points from CM

Once the shortest pathway is selected, it is exported as a vector holding an instruction of coordinate points that an agent must follow to reach the final destination. During each step, the agent updates its aimed target of the corresponding point. If there is a visible corresponding point that is farther in the progression on a direction vector, the aimed target is updated, and the agent progressively continues generation of the next movement steps. If the simulated step will cause moving out of the layout polygon, then the step is re-calculated until the placement of the next step is not correct. The movement simulation continues until it is not in the last step distance to the selected target. If the agent can potentially reach the endpoint, then the movement simulations transition it to the final destination. Reaching the exact point of the pathway end would require a tremendous amount of iterations. It could potentially not reach a final point at all. That is why the direct step simulations stop in an iteration before the last step. In other words, there is an approximate destination point that the agent has to fit into to conclude the movement simulation process.

Simulation of more than one occupant can be done using the same solver. Each agent representing an occupant can have its own pathway. If they meet in the same corridor or path, both the agents must switch sides, as it happens in real life. This situation might happen if the one agent is blocking the view of another to the aimed corresponding point. Each agent has its physical dimensions (width and circumference) that are implemented in the simulations. To simulate passing of the agent, each has an additional set of supportive corresponding points that can be dynamically included in other transition pathways vectors. A set of two supportive points is placed in a position perpendicular to the current vector turn. Each additional point is in a distance from the body centre equal to its circumference. If the agent blocks the aimed target, the software will update the pathway vectors. Included in that scenario, agents will aim towards a supportive point of another agent that is closer to them. This situation will happen if agents are opposing each other. If the agents are following a similar pathway, one will follow another until the previous target of the following agent is not visible. Simplified version of the transition algorithm is shown in a Figure 4.

Input Arguments
Poly –polygon of simulation; *Start_Poss* – Start position; *End_Poss* – Goal position;
F_Ang_Cd - Angular cumulative distribution function;
F_Step_Cd - Movement speed cumulative distribution function;
Fq_Time – operating time resolution; *I_T* – Initial turn; *i* – Iteration step; S_i - iteration step position;
T_i - iteration turns; *Rand* – random number (0-1); *Eq_Pt* – equial distance selector;
i=1
T_1= I_T
S_1 = Start_Poss
WHILE $\sqrt{(S_i(x) - End\_Poss(x))^2 + (S_i(y) - End\_Poss(y))^2} > \frac{F\_Step\_Cd(Rand)}{Fq\_Time}$;
i=i+1;
Step_Distance= F_Step_Cd(Rand)/Fq_Time;
Step_Turn= F_Ang_Cd(Rand)
Test_T_1 = T_{i-1}-Step_Turn
Test_T_2 = T_{i-1}+Step_Turn
Test_S_1(x)= S_{i-1}(x)+ Step_Distance +cos(Test_T_1)
Test_S_1(y)= S_{i-1}(y)+ Step_Distance +sin(Test_T_1)
Test_S_2(x)= S_{i-1}(x)+ Step_Distance +cos(Test_T_2)
Test_S_2(y)= S_{i-1}(y)+ Step_Distance +sin(Test_T_2)
IF TEST_S_1 *inside* Poly
Dist_$Test_1$ = $\sqrt{(Test\_S_1(x) - S_{i-1}(x))^2 + (Test\_S_i(y) - S_{i-1}(y))^2}$
ELSE
Dist_$Test_1$ =Inf;
END
IF Test_S_2 *inside* Poly
Dist_$Test_2$ = $\sqrt{(Test\_S_1(x) - S_{i-1}(x))^2 + (Test\_S_i(y) - S_{i-1}(y))^2}$
ELSE
Dist_$Test_2$ =Inf;
END
IF Dist_$Test_1$= Dist_$Test_2$ & Dist_$Test_1$ = Inf
Redo_step= Redo_step+1;
i=i-Redo_step;
ELSEIF DIST_$Test_1$= DIST_$Test_2$
Redo_step=0;
Select_S= Dist_Test(Ee_Pt(rand));
S_i=Test_S(Select_S)
T_i= Test_T(Select_S)
ELSE
Redo_step=0;
Select_S= min(DIST_Test);
S_i=Test_S(Select_S)
T_i= Test_T(Select_S)
END
END
i=i+1;
S_i = End_Poss

Figure 4. Simplified movement simulator algorithm

3.6 Even distance dilemma

During simulations, there is a chance that the agent will be exposed to conditions where it must select one particular direction. If both the connections will be even in terms of the distance, or the simulated angular distribution will deliver an even distance from both sides to the aimed target. It could be possible to assume that the selection of the direction is random, but this solution has to be backed up by experiment. To investigate this phenomenon, a series of experiments were conducted, where, in an improvised maze, monitored humans had to select their transition. The whole experiment was divided into six series (cases), where each human had their unique maze layout (Figure 5). Each maze was created using office desks, allowing participants to screen the whole space. It is possible to assume that each participant was aware of the direction that it was aiming to. Different maze setups were designed to investigate the influence of the entrance/exit placement on possible pathway selection. Data from this experiment were captured using the two depth registration cameras capable of covering the whole maze setup area. In the experiments, ten participants were involved (seven male and three female). During the experiments, each setup had to be executed ten times at a normal transition speed. Repetition of each maze was performed to check if there is any influence of task repetition, where participants could lower their focus and perform actions that rely on their automatic response.

Collected data were analysed in terms of the path section selection. Each maze had its entrance, middle corridors, and exit. Detection of the distribution of a particular selection of the pathway was done by analysing the entrance/exit of the maze with a detection where the side of the maze was used to move towards another side of the maze. Therefore, one setup generated twenty decisions per person. The results of the collected data distribution are summarized in Figure 5.

As expected, there is no particular correlation between the selections of the pathway, while all of them have a similar direction. If there is a pathway that is obviously longer than a more straightforward pathway, in most of the cases, such pathway will not be selected. Nevertheless, it is not justified to discredit selection of the longer pathway. Therefore, obtained distributions regarding path selections were implemented into the movement simulator module.

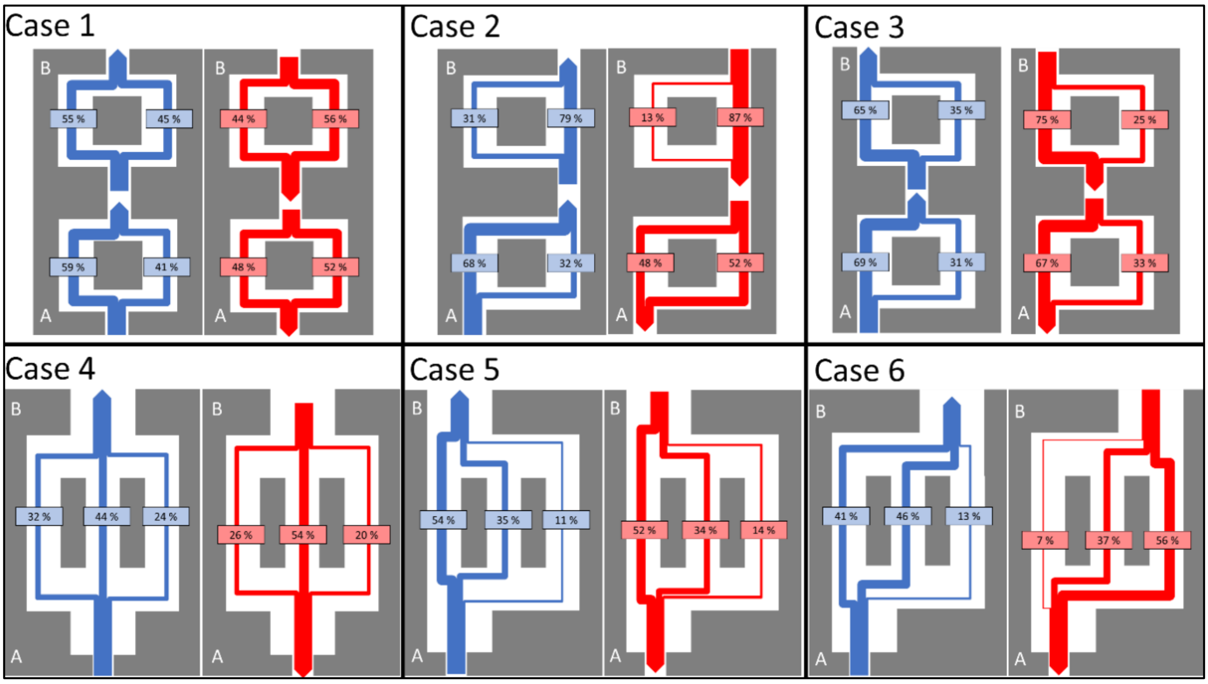


Figure 5. Movement transition experiment setup and transition vectors. Each case was analysed separately regarding aimed direction Each transition for A to B was coloured as a blue graph, and from B to A as a red graph

4. VALIDATION

The developed model was validated by following commonly practised validation methods included in the existing literature [46]. To do so, it is necessary to identify the baseline of the phenomena and compare its performance with the following scores variables: "Reaching the target", "Too many steps", and "Outside layout". The whole simulator operates on a fixed time resolution. Therefore, the time variable can be neglected. If the agent reaches a goal, it scores on a " Reaching the Target" variable.

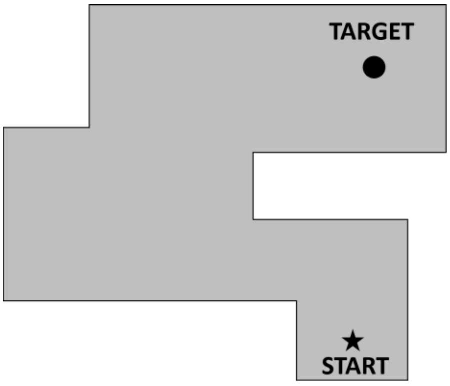
If the agent fails to transit into the target within ten times of steps (iterations) that in average are necessary (shortest distance divided by the average speed) the agent fails the transition.

In such a case. the transition scores on a "Too many steps" variable and ends simulation in that spot.

The developed module operates on the following five functionalities: cumulative velocity distribution (CVD), cumulative angular distribution (CAD), Shorter distance selector (SDS), floor layout detection (FLD), Even distance dilemma (EDD). Each functionality was described and defined in a subsection of the Methodology section of this manuscript. Each included functionality pays a significant role in re-creation of natural occupant movement. Lack of one or more functionality might generate a successful transition, but it might emerge due to the probabilistic chance. To check the significance of all the functionalities, it was proposed to test all the potential permutations of all functionalities scenarios where each of them could have status as ON or OFF. This will include all functionalities except EED. It does not influence the success of the pathway generation, but it might slightly increase the number of steps (iteration) if the dilemma is met. Therefore, it is a supplementary functionality that does not influence the success of the movement simulations. Each included functionality in the validation process can be implemented to the code as with status on or off. If FLD functionary is turn off, the agent has no information about the layout. It only has access to the initial and endpoint. Therefore, it will directly aim towards the endpoint of transition without concern of the surrounding geometry the obstacles. The rest of the functionalities (CVD, CAD, SDS) are considered as a status OFF when instead of using its discovered properties, its parameter is selected by random.

Consequently, CVD and CAD use the range of its distributions but do not use it for step selection. Instead, the variable is selected randomly. If SDS functionality is OFF, the agent chooses randomly one of potential steps.

In this validation procedure, there are sixteen different functionality scenarios. Previous studies have shown that typical daily transitions in a residential building are lasting for around 6000 seconds per day [47]. Each transition typically lasts for approximately 5 to 10 seconds. It is approximated that occupants are committing about 1000 transitions daily. To check how the developed model is capable of simulating one whole day, validation simulations were tested 1000 times. Each test was evaluated through the selected score variables. The baseline functionality scenario is the one where each functionality was set on a status OFF. Used layout for the validation and its results are shown in Figure 6.



	Status of Functionalities				Validation Variables		
Case	CVD	CAD	SDS	FLD	Reaching the target	Too many steps	Leaving the layout
1	ON	ON	ON	ON	949	0	51
2	ON	ON	ON	OFF	0	573	427
3	ON	ON	OFF	ON	0	0	1000
4	ON	OFF	ON	ON	844	0	156
5	OFF	ON	ON	ON	928	0	72
6	ON	ON	OFF	OFF	0	0	1000
7	ON	OFF	ON	OFF	0	1000	0
8	OFF	ON	ON	OFF	0	1000	0
9	OFF	ON	OFF	ON	0	0	1000
10	OFF	OFF	ON	ON	773	0	227
11	ON	OFF	OFF	ON	0	0	1000
12	ON	OFF	OFF	OFF	0	0	1000
13	OFF	ON	OFF	OFF	0	0	1000
14	OFF	OFF	ON	OFF	0	1000	0
15	OFF	OFF	OFF	ON	0	0	1000
16	OFF	OFF	OFF	OFF	0	0	1000

Figure 6. Validation geometry with model functionalities validation results.

5. Simulator sample results

To investigate abilities of the developed movement simulator, two type of tests were conducted, focusing respectively on general transition and pathway repetition.

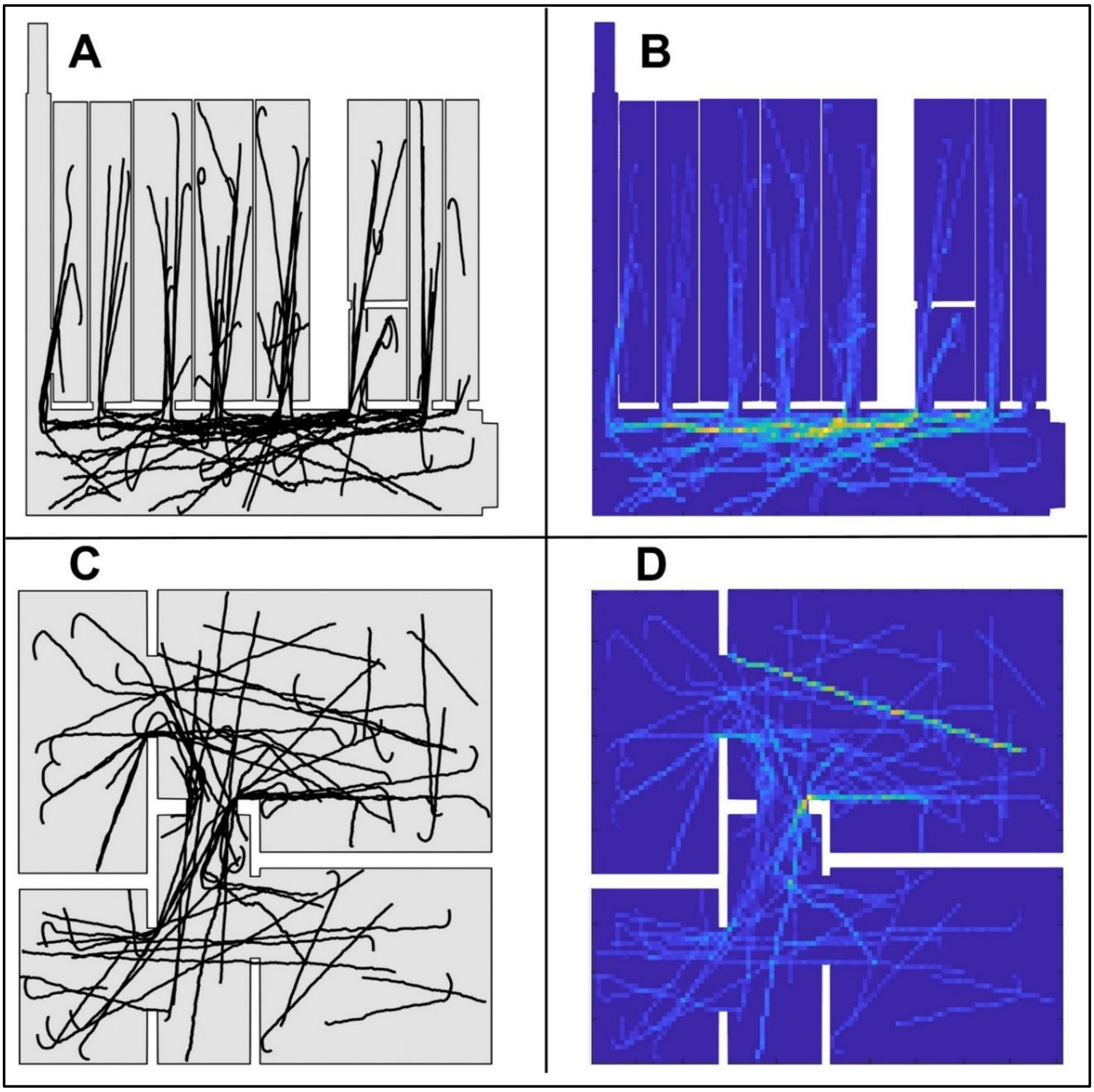


Figure 7. Simulation results for an office layout (A) and its heat map (B). Simulation results of a typical flat layout (C), and its heat map (D).

To simulate general transition, two zones were selected; a general transition inside an apartment and inside an office. Each simulation for this segment included the random positioning of the start and the end point. Each variation was simulated fifty times. Transitions inside these layouts are displayed in Figure 7 by the movement transition points and heat maps. Each heat map represents a cumulative value of an Agent's presence in a particular space, operating on a fixed resolution. Higher number of generated pathways could make zone layout blur and it would be difficult to recognize single pathway. Each heat map was generated in a resolution of one hundred times one hundred, and dimensions of the whole layout are the boundaries of the heat map.

To display the variability of the pathway repetitions, three simple layout scenarios were shown in Figure 8. A simple straight pathway transition, an elbow connection, and a straight pathway separated by the wall parallel to the corridor length are shown. The result of these simulations is displayed similarly as previous simulation.

Each simulated pathway is represented by a gathering of the points displayed on a layout heatmap. Each path is described by the vector that holds spatial information of each taken step. For the result purpose, the initial localisation of the movement was selected randomly in space. As shown in Figure 7 and Figure 8, no matter where the agent initialises its transition, it is capable of finishing its movement goal.

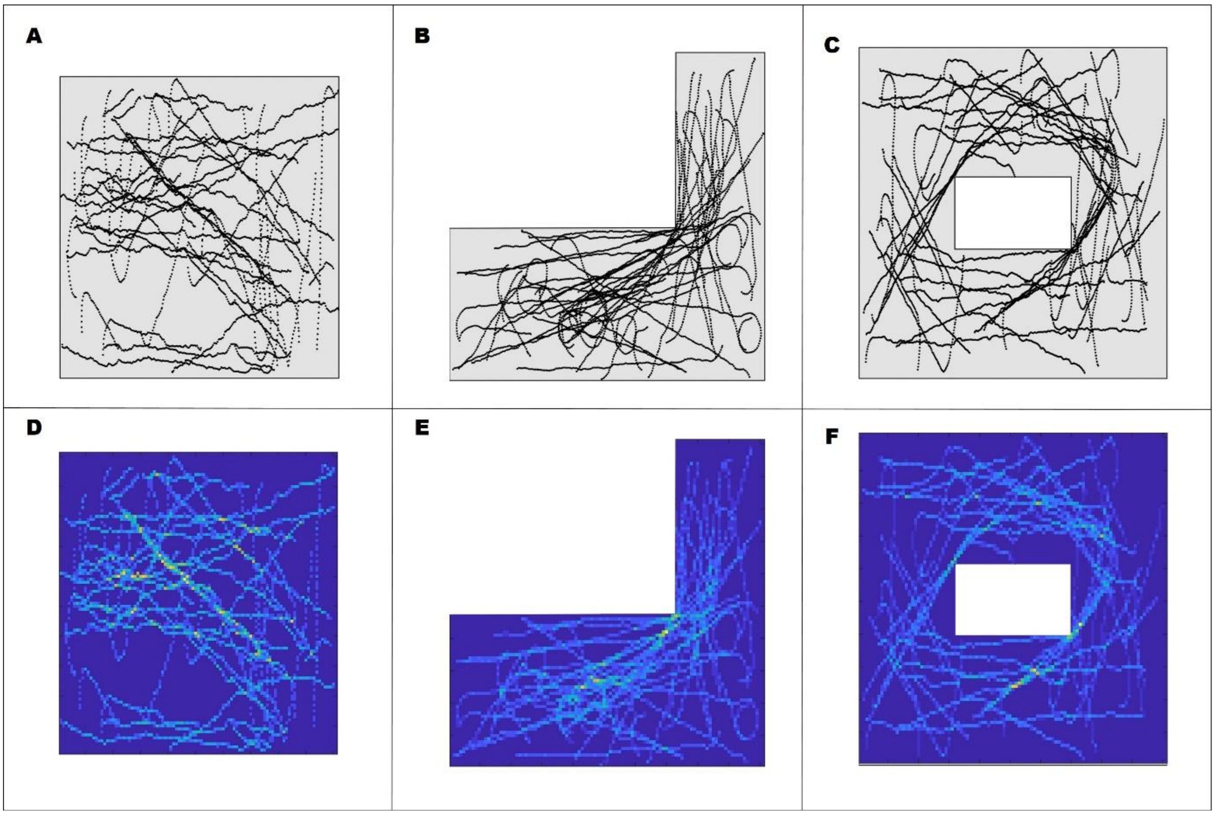


Figure 8. Simulation results for different layouts. Simple corridor (A), and its movement heat map (D). L-shaped corridor (B), and its movement heat map (E). Corridor separated by an obstacle (C), and its movement heat map (F).

If this application were implemented in BPS software, then there would be an initial and end movement point in a similar location, of building/zone exit. The whole transitions are aimed to be simulated continuously until the agent leaves the investigated area. Information about the agent location can be used to draw an occupancy schedule, but it can also be implemented to investigate occupant thermal comfort with high granularity. Ability to position the human body allows the calculation of a local radiant temperature. Additionally, the same step points can be used to probe data about local air thermal properties, if the used solver supported a multizonal simulation.

6. Discussion

The test of the developed movement simulator shows that it is capable of generating pathways that are not prescheduled. It operates on a simple coordinate system that does not require an extensive calculation power to operate. The general movement simulation process does not include a necessary preparation phase. This phase requires access to a polygon drawing that represents the floor layout. The process of vectorization operates on a raster picture. This makes the completion of preparation a time-consuming process. The vectorization is a one-time process not induced in the general computational performance test. The necessary computation time for the vectorization relies on the complexity of the given area if it covers a large space, or it has numerous amounts of holes area inside. The same situation concerns the description of the coordinate system. Once it is calculated, it can be explored until there is no significant change inside the building layout. Additionally, numerous possible corridors influence the calculation time process. General simulation of the transitions of each case took approximately five minutes, without plotting transition pathways.

It must be pointed out that each case was exposed to one thousand simulations, where each simulation had a mean value of three hundred steps, and each step was simulated in approximately 0.01 second. Such fast processing allows to assume that it is possible to simulate transitions of more than one occupant in a relatively short time. If such performance is maintained during the whole simulation procedure, simulation of the whole year of transitions can be done in twenty-four hours, with the assumption that each year an occupant spends 10% of its total time on a transition movement. Used computer hardware specification was described in the acknowledgement.

Tested layout scenarios were drawn as an orthogonal shape. A vectorization method would be able to handle the process of more diagonal shapes but not more opaque shapes. Any kind of rounding could be considered as a corner, formulating an advanced structure of a polygon at the same time. This problem could potentially be solved by simplifying the shape by fine resolution grain, or by the introduction of a round shape detection function that will immediately detect the existence of a rounded shape, and it will describe the shape with an arc-shaped vector.

Zone layout outlines are necessary to detect the corresponding points and to hold agents inside the layout. Their primary function is limited, but it can be extended. The whole zone can be multiplied and separated as a layer. Each layer can be responsible for different floor features such as the placement of the furniture, doors or electrical appliances. It can be done in the same way as it is organised in BIM software (e.g. Revit or Sketch Up). It can share similar modular architecture. Each included device must be described by the extensive metadata that hold information about device dimensions, localisation of coordinate points, and the list of activities it can be engaged in. An example of the simple scenario scene is displayed in Figure 9. Each activity had different corresponding pathway colours. All the included actions were kept in a pre-scheduled sequence. In this simulation, the agent was instructed to start from the home office zone and to sit in front of the desk. After that it was instructed, to enter the kitchen (red path), pick up a meal from the refrigerator (blue path), cook the meal on the stove (magenta path) and finally eat the meal while using the table in the living room (cyan path). Once the meal was finished, the agent had to wash the dishes at the sink (black path) and go out of the flat (yellow path).

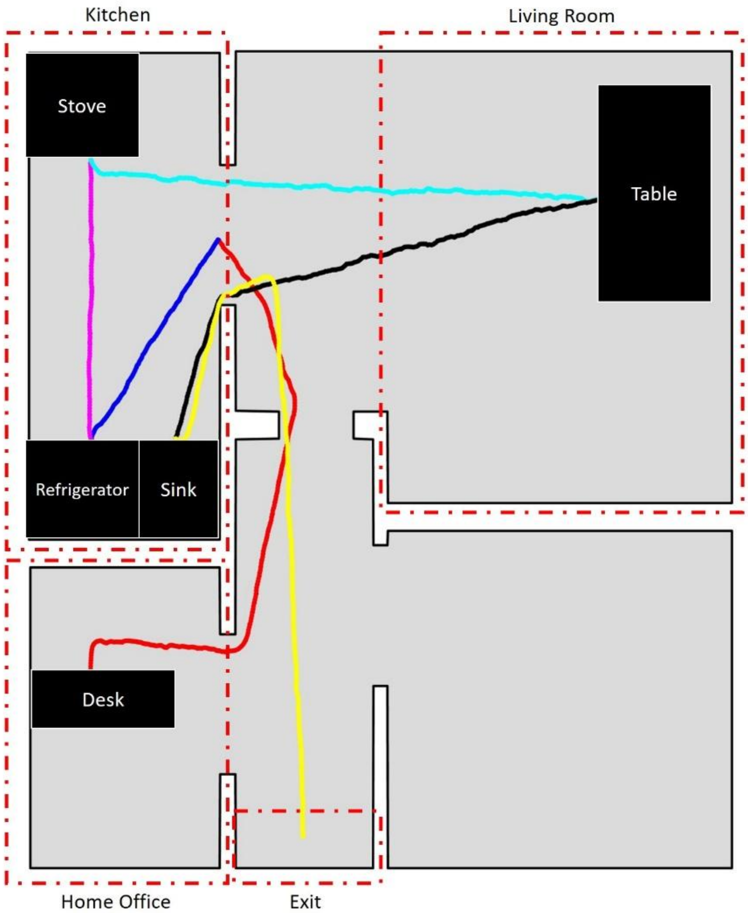


Figure 9. Simulation results of the sequenced movement inside the selected layout. Each taken pathway is coloured by the corresponding action.

Movement of the agent is represented by a singular point, but it can be extended to full body representation. Data collected via the depth registration technique allows for a formulation of the whole-body numerical representation. It can be transferred to the movement simulator as well. Projection of the body can be re-calculated by the defined number of points. Therefore, it is possible to generate numerous three-dimensional strings that represent points of the human body transiting inside the indoor space, which can be used to monitor how the agent is exploring and perceiving the given space. Information of the body turning and placement of the limbs can be used to sense the environment by using other numerical software such as IDA-ICE or ANSYS Fluent [11], [48]. Data obtained from these external sources can be used to generate a feedback loop for an agent to react on given environmental conditions if such rules are applied.

7. Conclusions

The current state of the building occupant transient agent-based model development can be considered to be a foundation of an artificial intelligent occupant behaviour model, but further progress requires more research. The current state of the model allows formulating a series of next tasks for the development of a comprehensive agent-based model enabling human-centric building design.

The movement simulator that has been developed delivers a new dimension for building energy performance simulations. Use of this application allows simulating all occupant transitions inside the buildings. It includes actions related to adjustment of the comfort, opening the windows or adjustment of the setpoints on the thermostat. All these actions require movement of the occupants to be conducted. As shown in the Results section, the tool can deliver the functionality of formulating a procedural generation of pathways taken by building occupants. It does not require an advanced artificial setup of the pathways, which can be considered a time-consuming activity. It allows to put the focus on the scheduling of the activity or programming the potential reactions of human behaviour. Therefore, that task can be introduced to a broader audience, not only to building design practitioners or scientist related to the field, but also to social scientists, behaviourists and psychologists. Use of this technique allows for an extraction of data about the position of the individual body. This information can also contribute to occupant behaviour thermal comfort models. Ability to probe data about indoor air states from numerical simulation allows for the introduction of the new numerical solver that reacts on a particular “sensed” condition. In consequence, it will influence simulated building energy performance by adjusting the indoor environment to its preferences.

The main functionality is simulated by the simple solver, which leaves significant space for the addition of potential modulators. The source of those triggers can be obtained from other future implemented modules of the building occupant transient agent-based model. Execution of the signal modulation inside the solver can be done by providing a set of additional variables in the decisions of the agent making the step. For example, while selecting the pathway, the main driver is pathways distances between the start and the end point. However, it is possible to influence the pathway selection by other parameters that could originate from other modules, e.g. possibility to fulfil other tasks on the fly, or preferable thermal conditions of a different pathway.

As shown in Figure 9, the agent can simulate pre-scheduled activities being “aware” of the placement of the features. This assumes that agent is familiar with the used space. Hence, it does not require permanent space recognition systems, such as Simultaneous localisation and mapping [49], [50]. Therefore, simulated occupants, i.e. agents behave, such as typical occupants of that building do. Implementation of the “first-time use occupants” module can be conducted in a similar simulation environment, but it requires a different computational approach.

Floor layouts used in the displayed simulations (Figure 7, Figure 9) were quite large, with a relatively advanced connection grid. In the future, the indoor layout connection grid should be decentralised. Use of one large connection grid should be avoided. Otherwise, it will generate an unnecessarily complex connection matrix to simulate. Each room can be separated by the doors, which can be considered a separator and coordinate point. Implantation of this feature will decentralise the connection graph, which will significantly reduce the complexity of the connection matrix. Simplification of the connection matrix will automatically accelerate the computation time. Additionally, if during a simulation, more than one agent was included, it would be necessary to constantly update the connection matrix by moving the position of supportive corner points from the agent. Operation in a one-connection matrix that would require such constant refreshment would generate unnecessary use of computational power.

The introduced foundation of the agent-based model can follow a given instruction of the activities/actions. No matter how complicated scenario is generated, the agent will be able to follow its instruction. Development of the tool that allows the formulation of the action instruction is not yet available. This feature will be addressed in the future research. Additionally, it is recommended to describe actions in a way that allows for a certain degree of freedom of a behavioural pattern’s digital representation. Each task should be described by the time that it should last, parameters that it might influence, and input arguments that might modulate its action. With such a comprehensive description, the agent would interact with the given environment more autonomously. Introduction of this parameters should be followed by a description of personal profiles of the occupants. Ability to describe and generate various profiles of occupants would allow testing their reactions to the given environment during the design. Occupant profiling should include parameters that hold a certain level of individualism, such as thermal comfort or hunger.

Access to all the mentioned functionalities can increase the accuracy of general building performance simulation. The implication of the presented simulation methodology can contribute to a better understanding of building occupants. A better understanding of occupant needs might contribute to development of the new, human-centric rules for building design and control. It can be used to identify limitation of already existing buildings and propose a solution that might optimise building energy use and increase the general well-being of occupants. The present movement simulation method would add a missing piece that links the dynamic behaviour of occupants with building design and simulation software.

Further extension of the present movement simulation tool will eventually grant the ability to develop a “digital twin” of the building. Where each object included inside real-building, has its digital representation in a software. As already recognised, humans play a significant role in building energy use. Therefore, their presence and activity must be included in every simulation of building performance.

Ability to generate high-resolution sampling of the movement patterns can benefit numerous applications. It can allow simulated occupants to probe information about the micro-environment surrounding them. In the same time it can introduce a threshold-based feedback control of the building control system. Not only does it allow to investigate the implications of the proposed heat, ventilation and air conditioning system, but it can also be used to benchmark building sustainability and resilient. Such a solution enables testing the security of the building and system design regarding the handling of various weather conditions. Oncoming global warming correlates with frequency appearance of hazardous weathers conditions such as heatwave. With the proposed application, it is possible to simulate dangerous weather conditions and check what is expected thermal stress that the human body will be exposed. Access to such information might influence future designed routines, where potential misconduct might directly affect occupant’s health security.

The idea of this model is to simulate natural occupants’ indoor transitions. The current stage of the model allows simulating transition of the occupant represented as one point in the plane, which is the current limitation of the model. Even if the position of the skeleton model will be described by a three-dimensional humanoid, it is not possible to re-create all of the natural limp pendular movements while transiting. Additionally, each interaction with an appliance or furniture in a room has no representation in motion-captured limb transitions. Skeleton model stands stiff in front of its target. The current model assumes a particular amount of time that occupant is interacting with its destination place. If both of this issue were addressed, it would open a possibility to simulate an occupant activity rate, by introducing a physical property to each occupant limb. Future research should focus on resolving this issue and delivering a promising tool for building performance simulation.

8. Acknowledgements

The data collection and storage method applied do not allow identifying the participants of the study. Therefore, this study does not require certification by an ethics board. The authors declare that they have no conflict of interest. For this type of study, formal consent was verbally delivered by the participants of the study. The authors do not endorse any specific brand or device developer. The study has not been sponsored or influenced in any other manner by private companies.

The computer setting for the measurement procedure was as follows: Intel® Core™ i7-4785T with a CPU of 2.20 GHz: 16 GB DDR3 RAM; Intel HD Graphics 4600. Using a different setting of hardware for the measurement purpose may influence the sampling time. This publication does not seek to promote any specific product or brand.

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