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Modelling Occupants in Buildings: Stakeholders' Workshop on Current Barriers, Challenges and Needs

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***Abstract**: This paper documents the findings of a workshop on occupant modelling in building performance simulation (BPS)-based design practice. Upon discussions with expert BPS users, researchers, and software developers in Canada, the current state and future needs of occupant modelling for BPS-based design were identified. These discussions identified the need for improving the occupancy, lighting, and plug load schedules and intensities in design codes and standards. It was reported that the capabilities of the BPS tools should be tailored for the needs of state-of-the-art occupant modelling. In addition, the need for training opportunities to raise awareness about the importance of occupant modelling in the BPS-based design practice was noted.*

***Keywords**: occupant modelling, simulation-based design, BPS tools, building codes.*

INTRODUCTION

Currently occupant behaviour is recognized as one of the most important sources of uncertainty during simulation-based building design process (Hoes, Hensen, Loomans, De Vries, & Bourgeois, 2009; Yan et al., 2015). It is considered as one of the main reasons for the gap between the simulated and measured performance (Gunay, O'Brien, & Beausoleil-Morrison, 2013). However, occupant behaviour modelling in simulation-based design practice has not been evolving the pace it has in research (O'Brien et al., 2016).

Presently, occupant behaviour is represented in building simulation in terms of simple static temporal schedules that do not account for the dynamic nature of occupants (Sun & Hong, 2017). For instance, the schedules indicate the fraction of the building occupancy present and fraction of electric lighting that is on. The schedules are often considered ineffective as they fail to account for the behavioural differences expected in different building design alternatives. For example, changes in the window to wall ratio are expected to affect the way occupants use their shades and lighting (Gilani et al., 2016), but the schedules do not account for the impact of design on the occupants' behaviour.

Designers and modellers often assume that occupants will behave in favor of the design objectives while reality indicates different situation (Andrews, Yi, Krogmann, Senick, & Wener, 2011; O'Brien & Gunay, 2015). For instance, designers and modellers may assume when selecting operable windows that occupants are going to open them for favourable natural ventilation when outdoor temperature allows and close them otherwise. However, what happens in reality is that some occupants either leave windows closed or opened for a long time. These simplifications in modeling (i.e. using static schedules) lead to an inaccurate representation of occupants in simulation-based design. Contrary to these common simplifying assumptions, it is generally accepted that occupants' behaviours are diverse and can be modelled stochastically (Lee, Trcka, & Hensen, 2014). The accuracy in modelling occupancy and occupants' behaviour is essential to achieve more reliable simulation predictions and to appropriately select from available design options (Gilani et al., 2016).

Therefore, occupant modelling has gained considerable attention over the past two decades. Researchers have been working on developing better ways to represent occupants in simulation-aided design. Occupant modelling has been studied through numerous research projects (e.g., IEA EBC Annex 66, ASHRAE multidisciplinary Task Group OBB), and the findings have been documented in more than three-hundred articles according to a recent survey of the literature (Gaetani, Hoes, & Hensen, 2016).

As a part of these efforts, researchers have developed statistical models that predict occupants' interactions with various building components – e.g., electric lighting, operable windows, thermostats, window shades. Often, these models have been built upon longitudinal data gathered from shared or private office spaces and homes using various sensing technologies

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such as passive infrared motion (PIR) detectors, photo-sensors and contact sensors (Gilani & O'Brien, 2016). Nevertheless, occupant modelling research has generally not been transferred to the BPS-aided design practice (e.g., for code compliance and design).

In an effort to bridge the gap between research and practice with regards to occupant modelling, a stakeholders' workshop was organized at Carleton University in Ottawa, Canada. Twenty-five experts with diverse backgrounds attended the workshop (see Figure 1). The participants were expert BPS users, researchers, software developers, architects, and educators. It should be noted that the perspective expressed by the authors of this paper do not necessarily reflect those of workshop participants.

The objectives of the workshop were to better understand the status of occupant modelling in the BPS community and to put forward a roadmap for future work in occupant modelling research, development, and education.

Figure 1: Stakeholders workshop, Ottawa May 1st, 2017

The workshop was organized as the first step in a large two-year research project aiming at: (1) establishing and documenting a ten-year plan showing to what extent can occupant modelling penetrate in the BPS community and building codes, (2) identifying the gaps in the BPS users' knowledge and the barriers against achieving this goal, (3) establishing and documenting, detailed incremental targets to achieve the end goal, and (4) identifying the most critical gaps, barriers and milestones to achieve these goals. The project is led by Carleton University researchers in collaboration with RWDI, Autodesk, Natural Resources Canada, and National Research Council.

This paper starts by describing the structure and methodology of the workshop. Then, a summary of the workshop results and findings are presented. The current practice in simulation-aided design regarding occupants modelling are identified, followed by stating the occupant modelling status in building codes and design standards. The capabilities and features of BPS tools related to occupant presence and behaviour are discussed, and recommendations for future work and research are developed.

METHODOLOGY

To approach the workshop objectives, experts in the field of BPS and tangential fields were selected and invited to share their experience and vision to accomplish progress in occupant modelling. The workshop was organized into three breakout sessions. Each session started with a presentation and ended with an open discussion. The presentations provided an overview about: the state-of-the-art in occupant modelling research, BPS tools features and capabilities and simulation-aided design processes and performance uncertainty. The breakout sessions were structured to cover three primary areas related to modelling occupants in buildings: (1) identifying the current practice and challenges in modelling occupants in the building design, (2) occupant modelling in building codes/standards, and (3) BPS tools capabilities and limitations. Each breakout session consisted of four groups of approximately five participants and a facilitator (i.e. a Carleton University researcher). Participants, through discussions and brain storming, tried to answer the questions as shown in Table 1. To summarize the workshop outcomes, participants feedback was categorized under four main topics as shown in Table 1. Different opinions were presented and compared to each other in the context of the workshop.

THE WORKSHOP OUTCOMES

The workshop results indicated the need for more research and development in two major areas. Of them, one is to prove the sensitivity of simulation predictions and design decisions to occupant modelling. The other is to improve the current modelling approach by updating codes and standards, developing BPS tools, educating designers and increasing the building owners', operators' and energy managers awareness.

The workshop participants indicated that the current occupant-related schedules are known to be inaccurate and needs to be improved. However, the absence of a more reliable alternative –with a substantial source of

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data- has prevented the adoption of improved occupant modelling methods. Moreover, the purpose behind the modelling or simulation process may not require a detailed representation of the occupants.

Currently, BPS tools are used for one of six purposes: code compliance (most cases), building certification (e.g. LEED), private public partnership (P3) projects (PPP Canada, 2017) , HVAC design, building design (e.g. net-zero building) and measurement and verification (M+V) as shown in Figure 2. Modeling for code compliance or building certification generally does not require detailed occupant modeling, unless it is specifically asked for by the client.

Table 1: Stakeholders workshop discussion structure

TOPIC	BRAINSTORMING QUESTIONS
State-of-the-art in occupant modelling research	1. In brief, how does occupant modelling affect the various professions (architects, engineering consultants, modellers, code officials, code developers)? 2. On the scale of purely academic to mainstream practice, where are we at on occupant modelling and where should we be now? 3. What are the current gaps and barriers (practical, theoretical, political) to incorporating occupant modelling into building code and design practice? 4. What should we set as short term (3 year) and long-term (10 year) goals regarding occupant modelling and simulation in practice? 5. What are the priorities on this theme regarding research, building code, and simulation tools?
Canadian building energy codes and standards	1. What are current obstacles and solutions to incorporating occupant modelling into code and standards? 2. How would we/could we model uncertainty in the context of code? 3. What is the appetite for occupant modelling from code officials, modellers, and clients? 4. How should we go about advancing the state of specific occupant-related schedules and densities?
Building performance simulation (BPS) tools features and capabilities	1. What modelling tool features are required for or would encourage better occupant modelling? 2. Are we doing an adequate job of modelling occupant comfort? 3. How should we go about addressing uncertainty (e.g., Monte Carlo simulation with hundreds of runs, a few extreme cases, etc.)? 4. How should we manage risk/uncertainty for buildings with absolute performance targets (e.g., net-zero energy)? 5. Is the stakeholder community (especially architects and building owners) prepared for full declaration of uncertainty?
Simulation-aided design processes and performance uncertainty	1. What role does occupant modelling have in building design (and retrofit analysis)? 2. What role could/should occupant modelling have in building design (and retrofit analysis)? 3. Should occupant modelling approaches vary by scale (e.g., room vs. building vs. community) and purpose (e.g., code compliance vs. design support)? 4. How can we exploit uncertainty of occupants? 5. How should we deal with the risk of inappropriate occupant assumptions?

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In addition, the scope of the state-of-the-art occupant modelling needs to be expanded to cover different building types, sizes and functions. Then, improved occupant models and the corresponding functionality will have to be incorporated in the existing BPS tools. This will provide practitioners with ready-to-use and more realistic approach for modelling occupants.

Participants also emphasized the importance of increasing the awareness of BPS users on occupant modelling and its related features in the commonly used BPS tools. Also, they expressed the need to educate building owners, operators and energy managers on the role occupants play in determining the energy performance of a given building.

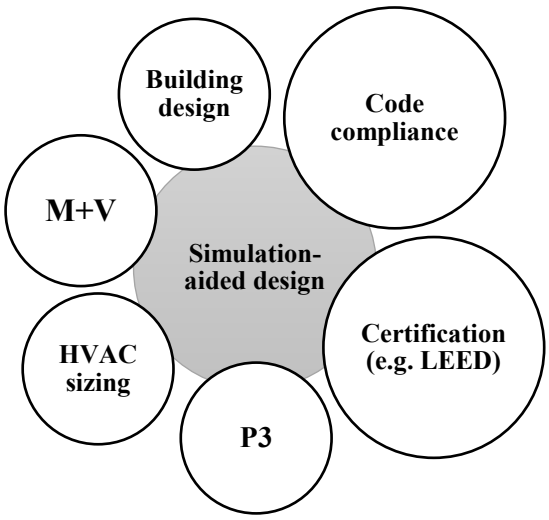

Figure 2: Current simulation-based design domain.

The participants proposed short-term and long-term goals to improve current occupant modelling practice. Proving the sensitivity of simulation predictions and design decisions to changes in occupant modelling approaches was the first proposed short-term goal. The next step will be updating the current outdated schedules to a better-informed schedule to better represent occupancy and occupants' behaviour.

For long-term goals, the participants expressed the need for updating the codes and standards regarding occupant modelling. Another long-term goal was to make the state-of-the-art occupant models available for practitioners by incorporating them in the BPS tools.

Status Of Occupants' Modelling In Building Design Practice

The status of occupant modelling in practice was the focus of the first session of the workshop. Some participants argued that occupant modelling might have an impact on their work depending on the purpose of the building performance simulation (BPS) and the goals of the modeller. For example, architects are generally concerned about occupant densities and egress. Engineers treat occupants as a source of internal heat gain which in turn affects the peak loads and HVAC sizing.

Attendees concurred that standard static schedules are nearly exclusively used to represent occupancy (i.e. presence) and occupancy related aspects (e.g. lights, plug loads, etc.). This means neglecting the fact that building design affects occupant behaviour. Some added that there is a slow movement towards more detailed representation of occupants and occupant behaviour. This can be seen in some net-zero building projects as occupancy needs to be represented accurately to achieve the performance targets. P3 projects also require detailed occupant models as the whole building life cycle is evaluated against the design objectives (PPP Canada, 2017). On the other hand, participants agreed that the state-of-the-art occupant models are solely used in research and are not yet used in design practice. Some argued that these occupant models can not be generalized as they were developed for specific buildings and validated under certain conditions.

Some participants expressed their belief that the current practice ignores the diverse nature of occupants. However, they also do not have more accurate models to use since occupancy and occupant behaviour are dynamic and diverse, so it is not easy to quantify in many cases. This ambiguity allows designers' and modellers' assumptions to be unregulated and inconsistent. For instance, they may rely on their past experience, or use schedules from similar buildings or the default ones. Using occupant modelling assumptions that do not ultimately correspond with reality could lead to inappropriate design decisions. They also indicated that the clients are not aware of the uncertainty associated with occupancy related aspects and its impact on the building performance. However, the majority of designers or energy modellers are not willing to

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jeopardise the trust of their clients by mentioning or emphasizing this uncertainty and its implications on the actual performance (O'Brien et al., 2016).

On another front, other workshop participants stated that, engineers usually do not use the same building model developed for code compliance to design and size the HVAC. Instead, they conduct independent HVAC design calculations, and in case they do use BPS, they tend to use conservative assumptions to avoid the risk of under-sizing (Djunaedy, Van den Wymelenberg, Acker, & Thimmana, 2011).

It was also stated that modellers often have limited time and budget to perform the required simulation process. This time and budget limitation play a major role in determining the level of modeling details. In other words, building modelers will typically not spend additional time or effort on modelling unless it is required by code or paid by building owners.

Overall, the participants agreed that current occupant modelling practice is not optimal and needs to be improved. The required improvement should include codes/standards and BPS tools as well.

Occupants' Modelling In Building Codes And Standards

Building codes and standards concerning occupancy and occupants' behaviour were the second topic discussed in the workshop.

Current building codes require the use of simple schedules with constant values based on designer's assumptions about occupants in both reference buildings and design alternatives. This approach might lead to inaccurate performance predictions and may negatively impact the design alternative selection. Hence, the existing codes and standards related to occupancy and occupants' behaviour need to be updated, given that practitioners are guided by these codes and standards.

Participants stated that the existing codes and standards do not offer alternative approaches for occupant modelling and do not have incentives to reward buildings on the accuracy and detailing of performance predictions. This means designers and modellers will carry on using the current approaches until more accurate approaches are introduced and mandated.

Furthermore, participants argued that current codes and standards include only schedules for presence, lights and electrical equipment, occupant densities, and power densities for lights and electrical equipment. This simple treatment is inadequate as it ignores the dynamic nature of occupants and their continuous pursuit for comfort (O'Brien & Gunay, 2015). Therefore, codes and standards should consider the interactions between occupants and the building. For example, current codes and standards do not account for building occupants' interactions with thermostats, operable windows, window shades, etc.

One group of participants stated that any proposed changes to codes will be scrutinized if it is not supported with a concrete evidence. Another group in the room questioned whether modelling occupants in buildings is so important that codes and standards should require more detailed approaches.

The attendees agreed that to improve codes and standards related to occupant modelling, practitioners (e.g. designers and BPS users) need to be actively involved in code development committees to convey the actual market needs to the concerned authorities. This can happen through workshops, meetings and surveys to get the practitioners feedback that identifies the gaps that need to be addressed and the areas need to be covered in the codes and standards. Moreover, it was also stated that the updated schedules should be developed for a number of different building archetypes.

BPS Tools Features And Capabilities

Most prevalent BPS tools include occupant modelling features with a varying level of flexibility to represent occupants and occupants' behaviour. For instance, EnergyPlus (DOE, 2018) enables moderate level of modelling details about window operation, shading operation, clothing level and lighting use. However, without the guidance of standards, practitioners will have to either keep the tool defaults or make assumptions based on their experience. In order to deviate from defaults BPS users must have a rationale, as doing so is associated with some degree of perceived or real risk.

The attendees indicated that they are not utilizing all features of their selected BPS tool and sometimes they are not fully aware of these features. They also agreed that there are several features in BPS tools that enable

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users to perform a more detailed modelling of occupants and occupants' behaviour. This includes using data from clients or similar buildings in operation to create schedules for presence, lights, electrical equipment, shading, clothing, etc. Another approach would be performing a co-simulation by integrating more than one BPS tool to perform the simulation. This approach enables modeller benefit from a wide range of capabilities offered by different simulation tools. Users also can modify the BPS tool to accommodate the state-of-the-art occupant models. For example, EMS (energy management system) in EnergyPlus enables users to write custom scripts to incorporate new occupant models into the building energy model. However, using these capabilities requires additional skills, time, and budget which are not always available. On another front, building owners are not prepared to shoulder extra costs that are required for further detailed building models. Therefore, practitioners seem not to be assigning any additional time or effort for modelling occupants unless it is worthy in return.

Participants suggested that adequate efforts are not being done to model occupant comfort. Some argued that modelling indoor air quality had advanced to a decent level while modelling visual, acoustic and thermal comfort is still immature and need more effort and research to be incorporated in simulation tools. This emphasizes the aforementioned fact that occupants' behaviour is often driven by occupants' discomfort.

One more driver behind underutilizing the capabilities of the BPS tools is the BPS user. A substantial portion of the workshop participants learned to use tools they use by themselves or through a one to two-day workshops. This does not provide the necessary knowledge of the tool and its features and capabilities particularly with regards to more detailed aspects such as occupant behaviour. Therefore, in order to achieve the desired level of modelling skills, modellers need to receive a complete professional training on their selected tool. The training should be comprehensive and cover all features of the BPS tool. This will equip users with the necessary skills to utilize all useful features of a tool and detect faults. The training can be provided through the BPS tool developers, educational and professional institutions, or organizations like International Building Performance Simulation Association (IBPSA).

Another proposal was tabled by some participants is to develop a tool that can generate custom schedules. The way this tool should work is the building owner will have to complete a survey about occupancy and operation aspects then this data will be used to generate custom schedule. This approach would require clients/owners that have better knowledge of their building function and are able to predict the occupancy pattern.

UNCERTAINTY IN SIMULATION-AIDED DESIGN

The simulation-aided design process and the occupants' associated uncertainty were the next topic of discussion. Simulation-aided design is always associated with a certain magnitude of uncertainty. This uncertainty is dependant on several factors such as occupant behaviour, weather, tool algorithms, user errors and material properties.

According to the workshop participants, code compliance is the most popular reason for conducting building performance simulation. The focus of this type of simulation is proving that a given design alternative meets the energy consumption targets set by the code. In this kind of simulation, occupants are simply represented using the static schedules and are considered sources of internal heat gain rather than active agents in the building. Some workshop participants mentioned that occupancy data is illegitimately manipulated by some modellers to achieve design goals.

In addition to code compliance, BPS is rarely used for HVAC design and sizing (Djunaedy et al., 2011). When used, HVAC designers use the peak values and add a high factor of safety and create their own model for sizing purpose. BPS is also used as well to model P3 project, measurement and verification (M+V) and net-zero projects where the whole life cycle of the building is considered and monitored.

It was also argued that the way occupants behave is largely influential on building energy use. Occupants, while seeking to achieve or recover their comfort, will interact with building components: opening windows, closing shades, changing thermostat setpoints, switching lights on/off, etc. These occupants' actions are often used to restore comfort but then left in the state for an extended period (O'Brien & Gunay, 2015). The occupant might open a window to ventilate the space and may leave it open for days or weeks or

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switch the lights on when daylight level is low and leave it on for long time. These actions affect the building energy use significantly and are not considered by designers or energy modellers when using the traditional approaches of modelling occupants. Thus, the aforementioned stochastic and diverse nature of occupants is challenging for designers and modellers as they have to deal with this great uncertainty and mitigate its effects.

Turning the uncertainty to an opportunity was suggested by some workshop participants. An opportunity of producing a more robust design that mitigates the impact of occupants behaviour on building performance (O'Brien, 2013). This approach requires better understanding of building occupancy and occupants' behaviour. Engaging building owners in the design and from collected post occupancy data from similar buildings are ways that help understand occupants' behaviour.

Some experts stated that the uncertainty of occupancy, if identified, can be used to achieve saving by avoiding equipment over-sizing (e.g. HVAC) when designing for the actual occupancy and occupant behaviour. Another group of participants suggested that adding margin of errors to the design assumptions can help offset the uncertainty in prediction. Another proposal was tabled to produce a range of performance predictions instead of fixed-value predictions would help planning for uncertainty. This means the modeller needs to perform simulation multiple times using inputs low, medium, and high energy-using occupants. Alternatively, a continuous distribution representing the spectrum of occupant types could be sampled using Monte Carlo simulation. Results can be presented in the form of a range of performance predictions from the worst to best scenario. However, this approach might encounter time and budget restrictions as it requires more time and effort compared to the typical simulation process.

Some participants recommended having a built-in uncertainty feature in the BPS tools would help account for uncertainty and reduce inaccuracy in building performance predictions.

Generally, attendees agreed that uncertainty in simulation-aided design should be avoided. However, if uncertainties are identified and quantified, there will be opportunities to produce more robust and realistic performance predictions and hence rely on calculation risks.

RECOMMENDATION AND FUTURE WORK

The workshop was the first step of a larger project that aims to produce a long-term vision to reach advanced standardized occupant modelling in simulation-aided building design practice.

The outcomes of the workshop indicated the need for:

(1) Collect data from buildings in operation to better understand the occupancy patterns and occupants' interactions with buildings.
(2) Broaden the scope of data collection and analysis to include different building types, sizes and functions and to consider different climates and cultures.
(3) Update the current occupancy and occupancy related schedules based on research findings.
(4) Standardize a way for clients/owners to report information.
(5) Create a tool that can generate custom schedules based on information provided by building owners. To standardize data collection from building owners, a survey should be developed.
(6) Engage practitioners actively in the code committees and development process.
(7) Incorporate the state-of-the-art occupant models in BPS tools.
(8) Develop training material (user manuals, hands-on workshops, etc.) to teach BPS users about theory and application of occupant modelling.

For future work, the first step will be conducting sensitivity analysis to verify the impact of occupant modeling alternative on simulation predictions and design decisions. There after, a road map will be established for the planned incremental advances including setting priorities, overcoming the barriers and filling the gaps in knowledge, technology and users regarding occupant modelling as shown in Figure 3.

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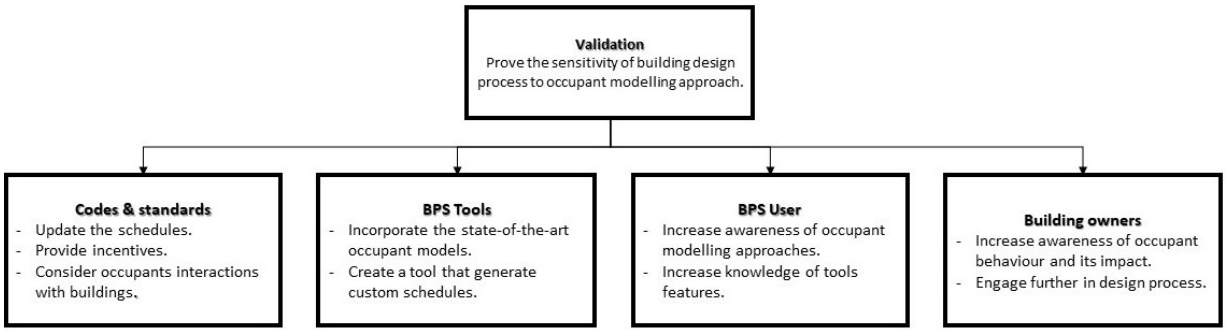

Figure 3: Proposed improvements to current occupant modelling approaches.

CONCLUSION

This paper summarizes the key findings of a stakeholder workshop on occupant modelling in simulation-based design practice to identify its status in simulation-based design.

This field is still considered in its infancy in terms of research and implementation despite its proven impact on building performance predictions (Gaetani et al., 2016).

The purpose of the workshop was to obtain the feedback from a sample of stakeholders based on their experience in modelling buildings, developing related codes and standards and their vision on how the occupant modelling approaches and development should advance. This will assist in establishing the required technology roadmap that guides the development and advancement in the field of modelling occupants in the long term.

The workshop tackled the key issues related to modelling occupants in buildings. The participants feedback indicated the need to take the first step immediately by proving the sensitivity of simulation predictions and design decisions to different occupant modelling approaches. This should be associated with post occupancy data collection to enable further research and more analysis to occupancy and occupant behaviour patterns.

As a short-term plan, workshop participants proposed using the collected and analyzed data for updating the existing occupancy schedules with more informed and up to date ones. The scope of updated schedules to consider different building types, sizes and functions. Moreover, they proposed the need for developing a tool that can generate custom schedules based on client-filled survey.

In the long term, the attendees concurred that there is a need to update the related codes and standards to include more details and to account for occupancy aspects other than presence and loads (e.g. equipment and lights). In addition, BPS tools needs to be developed to accommodate the state-of-the-art models in an easy to apply way to make it convenient for practitioners to use.

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