People who? Why occupant behaviour modelling is not (yet) included in the design workflow

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Abstract
People can be modelled as movement (pedestrian modelling), presence and behaviours. The modelling of people is particularly important during the building design phase for building safety design, building architecture and engineering (AE) design and for building performance analysis. While pedestrian modelling is part of the typical design workflow, presence and behaviour modelling seldom finds applications in practice. This paper uses first-person interviews to shed some light on why people modelling and its design implications are still poorly understood, what are the main barriers to overcome, and what scientists and researchers can do to ensure a better penetration of models in practice.

Key Innovations
- Interviews to practitioners and existing research are used to identify the current barriers to incorporate Occupant Behaviour modelling in the design workflow of practitioners.

Practical Implications
The challenges for incorporating Occupant Behaviour (OB) modelling in the design workflow are reviewed and practical actions are suggested to include in design workflows OB.

Introduction
Building simulation is acknowledged as an important tool to aid building design and operation [1]. This reality is well-reflected in the academic environment. The search engine ScienceDirect reveals a growing number of publications whose titles contain the keywords ‘building simulation’ and ‘design’ during the last two decades (see Figure 1), peaking at about 19k publications in 2019. Notable publications include [2], [3], which specifically target the challenge of a more effective use of simulation in building design. However, simulation tools are not free from uncertainties and limitations. Among others, the modelling of people presents a challenge. People are complex and unpredictable. They have different preferences, set points, working styles, lighting levels, and use and life patterns. Moreover, the very buildings they inhabit will affect their behaviours and their flow patterns. People modelling can be categorized in three groups: movement; presence; and behaviour (Figure 2). The following applications to people modelling during design have been identified [4](Figure 3):

- Building performance analysis: energy performance analysis (from component to whole building) and comfort performance analysis (people presence and behaviour, or OB);

![Image](https://doi.org/10.26868/25222708.2021.30590)

Figure 1 ScienceDirect publications whose titles contain the keywords ‘building simulation’ and ‘design’

![Image](https://doi.org/10.26868/25222708.2021.30590)

Figure 2 Categories of people modelling

- Building architecture and engineering (AE) design: circulation design (people movement) and HVAC sizing (people presence and behaviour, or OB);
- Building safety design: crowd management and passenger flow analysis (especially relevant in public buildings [5]), people movement and structures vibration subjected to crowd loads [6].

Different types of models are available for people movement, presence and the different aspects of occupant behaviour, as well as for different simulation purposes.
and building typologies. The modelling of people movement for circulation design, safety design, crowd management and passenger flow analysis is well-established in the architecture and engineering practice [7]. In contrast, presence and behaviour modelling falls short of implementation in the design workflow. Occupant behaviour (OB) is also referred to as human-building interaction and people/user/inhabitant behaviour, and it includes people presence (or occupancy) and behaviours within buildings that affect building performance or occupant satisfaction with buildings. OB modelling is useful for building performance analysis and HVAC sizing [8](see Figure 3), from the very early stages of the design process.

IEA EBC Annex 66 [7] and Annex 79 [9] have resulted in a rapid improvement of the state-of-the-art in occupant behaviour (OB)-related research. OB research for building performance simulation (BPS) mostly focuses on developing new models to describe occupant presence and occupant interaction with the building systems, on reviewing and validating existing models, and on data-collection to inform new models on the energy implications of occupant behaviour. The emerging research focused on the application and applicability of the existing models is reviewed in the following section.

![Figure 3 Applications of people modelling during the building design phase.](https://doi.org/10.26868/25222708.2021.30590)

**Literature review**

Roetzel et al. [12] addresses the issue of OB modelling during the early design stages. The paper focuses on the first two design stages, the pre-design stage and the sketch design stage, in which the environmental optimization potential is the largest. Clearly, early design stages are particularly challenging for OB modelling due to the lack of knowledge on actual occupant needs and requirements. Meanwhile, BPS tools require input with a higher level of resolution, which obliges BPS users to make several assumptions. These assumptions have a strong impact on the predicted building performance and they can lead to overestimate the beneficial impact of design decision by a factor of five or more [15]. In this sense, Roetzel proposes an ideal and worst-case scenario approach, whereby extreme cases are explored for each aspect of occupant behaviour to consider a wider range of possible behaviours. Gaetani et al. [20] also incorporates this approach in the wider fit-for-purpose rationale. The authors highlight how ideal and worst-case scenarios may not be predefined, due to the conflicting influence of OB on building performance. Moreover, scenarios should be deployed only for those aspects of OB that are significant for the investigated performance indicators to increase the efficiency of the process.

OB modelling based on in-situ monitoring of occupants in existing buildings provides an alternative manner to incorporate actual OB during the design workflow. However, bespoke OB models are only possible when data is available on the occupant requirements, which is usually the case of retrofit projects or new buildings designed for known occupants. The final recipients of a building are often unknown, and even when known the developer is typically interested in keeping a high degree of flexibility. Santangelo et al. [21] showed the importance of monitoring and modelling OB to support decision-making process of renovation strategies for public housing stock. Naspi et al. [17] used in-situ monitoring to develop tailored OB models for specific retrofit design. These bespoke models presented higher accuracy than standard models, but there is still a large degree of uncertainty given by the large number of factors influencing the response and behaviour of occupants. In this sense, mock-up design, interviews [22] or virtual reality [23] could provide aid tools to predict occupant response and support occupant-centred design.

Lastly, since OB is often misunderstood and a discrepancy between designed and real building performance, a possible solution to bridge this gap is the design of buildings whose performances is robust or, in other words, show little variations despite of alternating occupants’ behaviour [24]. An example of a robust design is a façade that is designed with building features that slow down the response of the envelope to changes in outdoor conditions and, hence, stabilize the indoor temperature to comfort conditions, such as fixed shadings or higher thermal mass [24]. However, robust design should never imply a loss in occupant personal control, which is paramount to occupant satisfaction [25], in change of higher performance, but rather prevent occupant discomfort and related maloperations of the system.

The methods proposed in literature to implement the appropriate OB modelling for building performance analysis are generally time-consuming, require significant domain expertise, lack clear explanation, and/or are
unclear about the actual benefits. Moreover, the typical architectural tools often do not allow for a fast and intuitive analysis of the impacts of OB on building performance and in turn the impacts of a given design on OB.

An overview of people modelling capabilities in the most widespread architectural tools follows next.

**Tools**

The lack of appropriate consideration of occupant behaviour in the design workflow is understood by reviewing the OB modelling capabilities of tools commonly used for design. The predominant digital design workflows in architectural practice use Revit [26] and Dynamo [27], or Rhino with Grasshopper plugins [28]. Some of these visual scripting environments do incorporate more sophisticated simulation models and engines such as Diva [29] or Ladybug [30], and experimental studies attempted to incorporate agent-based models and techniques. Most of the emphasis seen in literature as well as in practice is focused on structural optimization and form finding, rather than on building performance including human behaviour and preferences. When looking at the predominant toolkits of designers, it is notable that load calculations (structural, environmental, and human occupancy) are historically and still predominantly after-thoughts. While we have seen an uptake of form finding and structural optimizations tools (Kanagaroo, Octopus, Galapagos), environmental simulation and analysis tools (Honeybee, Ladybug, and Diva), pedestrian flow and evacuation tools [31], there is still a significant gap in the incorporation of OB in design practices and workflows based on empirically validated simulation models. However, findings from OB research could be expressed using tools that show process flows in a physical space. These process flows could be included in architectural software such as AutoCAD, Revit and Rhino. An example of these applications is the use of plug-ins based on Space Syntax [32] for Revit [33] and Grasshopper [34], developed to analyse the impact of urban design on people. Hereunder, the current methods to incorporate OB in Revit and Grasshopper are presented.

Revit utilizes schedules to provide information about occupancy assumptions for different building types used during energy analysis. These schedules are based on ASHRAE standards. The other operating schedules for each building type (such as lighting and HVAC) are based on the occupancy schedules for that building type. To manually change the occupancy number for analysis, the user is required to: i) place spaces in the model; ii) set the Export Category in Energy Settings to Spaces; iii) select each space in the model; iv) in the properties palette under Energy Analysis, modify the People parameter with the desired number and heat gain per person; v) run the energy analysis again to see the updated results. This means Revit users are required to undergo five manual steps to change their options regarding occupancy, provided that they have the information to make appropriate assumptions. Other OB aspects directly related to occupancy and advanced modelling formalisms seem to not be supported.

Grasshopper interacts with several simulation-based environmental plug-ins such as Ladybug, Honeybee for energy analysis and includes components for single and multi-objective optimizations (i.e. Galapagos and Octopus). Zani et al. [35] propose using Octopus to investigate different occupancy combinations and then feed them back to the Grasshopper environment. The tools that are commonly used in the architectural practice do not support a flexible and appropriate modelling of OB, they often need external plug-ins and the methods proposed in literature are not tailored for such tools.

Consequently, design decisions, especially in early design stages, are rarely informed by people presence and their behaviours. This might present a missed opportunity for architects and engineers to better address the human needs during the design phase, and to gain further understanding on their implications related to sustainability and energy efficiency.

Because of the lack of studies focusing on the design implications of OB modelling, the relatively young nature of the research field, and the lack of user-friendly tools, the integration of OB modelling in the design workflow of practitioners is almost non-existent. However, OB modelling would be most useful in the early design stages, where it has most potential of influencing design decision-making towards occupant-centric buildings.

This research investigates current practices of OB modelling for practitioners. We try to posit the causes for why OB modelling is not (yet) part of the design workflow. The research enumerates a set of gaps in the designer workflows as they relate to the incorporation of humans, human behaviour, and their critical effects on building performance. Ultimately, we propose a set of actions to ensure a better penetration of OB modelling in the design workflow.

**Research questions**

Our research objectives are to enumerate the gaps in the simulation tools that are and/or should be integrated into the architectural designers’ quotidian workflows. In relation to this objective, we ask the questions:

1) What is the current practice to incorporate humans in the design workflow?

2) What are the barriers to incorporate OB in these workflows?

3) What should researchers and scientists do to further integrate their findings, models and suggestions into the design practice?

**Methods**

The results presented in this paper are based on structured interviews conducted with a set of design professionals. Where possible, the emerging opinions are complemented...
by findings from literature review. We conducted 11 face-to-face interviews with leading practitioners in the field of architecture (please note that direct quotes from the interviewees are reported in the text in quotes “”). About half of the practitioners work at Arup, while the remaining respondents work for other leading architectural firms. While the dataset is far too limited to allow for any statistical consideration, the answers should work as insightful conversation openers for the IBPSA community.

Results

What is the current practice to incorporate humans in the design workflow?

The interviewed practitioners generally agreed that the workflow depends on the specific project and client. As a rule, the design project has an iterative nature, with a loop between creative teams and technical consultancy as shown in Figure 4. Generally, the Royal Institute of British Architects (RIBA) design stages [13] were perceived as a useful categorization of the activities carried out during the design process.

It is interesting to note how the creative and modelling teams are generally two separate teams, and this segregation is accentuated when the modelling occurs out-of-house. It is ultimately up to the creative team to decide to incorporate the advice of the modelling team and to which extent. The interviewees stated that aesthetics and space usage are priority in their design practice, “unless the client has a strong vision to do, for example, with sustainability, culture, or tech”. As already shown in Konis and Selkowitz [14], energy and environmental analysis tools are in fact rarely used to inform design decision-making in early design stages. The vision of the client is therefore important as it has an impact on the design process (e.g., exploration of different scenarios or higher requirements for occupant wellbeing). The consideration of people as the direct recipients of the design varies according to building typology and design stage.

Humans and their behaviours are considered in a multifaced fashion, which includes:

- **Experience**: consideration of the social and cultural context of a project from the outset of the workflow; this is based on experience and on past examples of similar projects in the same location, e.g. how well the design was received.

- **Circulation design**: modelling people movement (also referred to pedestrian modelling) can be employed to better understand people flows and interactions. This type of modelling allows to inform/dimension the floorplan design and “squeeze more juice” out of the building design in terms of space usage. Different tools are available according to the different design stages and building typologies.

- **Building safety design**: pedestrian modelling is also employed to verify building safety and evacuation, to guarantee the expected experience also in case of emergency, and to comply with regulations.

In contrast, presence and behaviour modelling, which are most useful for building performance optimization and HVAC sizing, are not widely accepted as part of the design workflow, despite the importance of occupant modelling for decision-making during the building design process [15]. OB modelling is perceived as specialist domain, with an interviewee stating that “we don’t do [modelling], we hire a consultant to do that”. Even so, since the design workflow is usually a compliance-based design process rather than a performance-based one, the focus of building simulations has traditionally been to just meet standard requirements. Practitioners report adopting default values from standards (such as DIN 18599 [16] for non-residential buildings), or variations based on experience. Assumptions are not clearly shared within the design team and their implications are rarely fully understood. If scenario analysis is carried out, the scenarios are typically based on individual experience and no robust methodology is in place. This result also emerges by Naspi et al. [17], where bespoke monitoring of occupant behavioural patterns inform the customized OB modelling assumptions to the purpose. However, such assumptions are not widely accepted upon practitioners since they are based on experience or on the results of in-situ monitoring campaigns and depending on the purpose of the simulation.

![Figure 4 Typical workflow followed by architects and designers during the design process.](https://doi.org/10.26868/25222708.2021.30590)

Practitioners generally felt that the current way to incorporate people and their behaviours in the architectural practice is not appropriate. People modelling
should be different according to the design stage [18]; OB should be considered at all stages, and most importantly at the start of a project (concept design), when the massing and layout of a building is still under discussion [19]. The interviewees highlighted the role played by building typology (“In all buildings people are super important, but in some they’re more important”) and the challenge given by the fact that the final recipient of a building is often unknown (“We’re interested in designing all things to all people”). A renewed interest in OB modeling emerges as a result of standards focusing on operational performance, such as the National Australian Built Environment Rating System (NABERS) and NABERS UK.

The main benefits perceived by the interviewees in incorporating appropriate people and OB modelling were:

- **Experience**: improving the overall design of the building or space and how it is experienced by its users
- **Productivity, health and wellbeing**: improved mental and physical conditions of building users, by providing spaces that lift people moods and enable their target activities at best
- **Comfort**: better thermal, acoustic and visual comfort for people
- **Space usage**: better space utilization, avoiding “dead spaces” in offices and entertainment buildings
- **Planning and sizing**: more reliable and fine-tuned sizing of HVAC and other systems
- **Energy**: more accurate calculation and prediction of energy use; possibility to detect system failures
- **Connection**: better understanding of the building concept and systems by its users

**What are the barriers to incorporate OB in these workflows?**

Several barriers to incorporate OB modelling in the design workflow emerged from the interviews. The barriers can be grouped in three main categories: stakeholders, software and feasibility.

**Stakeholders**

The barriers related to stakeholders concern both the design team and clients. It is perceived that both groups are affected by a communication problem; the language of OB modelling still feels very dry and technical, lacking poeticies. The very term “occupant behaviour” feels distant from a design project; “people-centric” is perceived as a better alternative. There is a need to overcome communication barriers with clients and inspire them towards people-centric designs (“Our clients want joy and surprise – not a dry spreadsheet”). Onboarding the clients emerged as a necessary first step towards more appropriate OB modelling. To do so, “the benefits [of spending more time on the modelling] must be made clear”. “How can we impress [our clients] designing for OB?”.

The benefits of OB modelling and their design implications are still perceived as unclear (“We must prove that there are either cost or quality improvements”). Indeed, [36] illustrated that the second most important reason not to include OB modelling as a standard practice in the design workflow was lack of understanding/education. There emerges a need for upskilling. Ownership is also an issue. For example, the performance gap is perceived as “not really the domain of architects”.

Work on removing the design team barriers (i.e. improving communication, understanding, collaboration and ownership) will enable to onboard clients on a people-centric vision that includes post-occupancy evaluations. Such a vision is today still uncommon.

**Software**

The barriers related to software can be further split in two categories: design tools and OB models.

Attia et al. [37] extensively explored whether building performance simulation tools are generally viewed as architect-friendly or not by means of surveys. While the authors did not specifically consider OB modelling, some of the findings are helpful to map the barriers for a wider implementation of OB modelling during the design stage. For architects, the most important criterion concerning usability and graphical visualization of BPS interfaces was identified as the graphical representation of output results [37]. This need was confirmed by the interviewees. In terms of information management, the creation of comparative and multiples alternatives is of paramount importance. Architects want to have confidence in creating real sustainable design and obtain a quick performance analysis that supports decision-making. The interoperability of the performance model with 3D drawing packages (Revit, Rhino, Maya, SketchUp, 3DS Max, etc.) is seen as essential. Generally, when asked to identify the most important features of a simulation tool, most architects responded integration of intelligent design knowledge base to assist decision-making, followed by friendliness of the interface concerning usability and information management and interoperability.

Generally, there is a lack of platforms that allow for integrated dataflows during design process. For example, people movement, presence and behaviour modelling could be integrated, if needed.

People behaviours are very complex and tackling people modelling is necessarily an interdisciplinary, collaborative effort. The current modelling practices still include high levels of uncertainty and it is questionable whether comprehensive models make sense [38]. Validation and verification require high resolution dataset, whose collection was traditionally very time-consuming.

**Feasibility**

The barriers related to feasibility include: budget, time and effort, standards and occupant feedback.
Budget and time pressure on projects result in avoiding everything that is not perceived as high priority. One interviewee mentioned that “typically, we would just maximize the office floor plate to match the module as revenue increase for contractor”. When asked about the biggest barrier to more appropriate OB modelling, most of the respondents of [38] also identified time and effort.

Building codes and standards are perceived as prescriptive and backward-looking, more of a checklist than an actual tool to encourage better design. Current standards have a superficial consideration of occupant behaviour, considered only as either basic lighting and occupancy schedules for simulation models or minimum requirements for personal control of lighting, heating and ventilation systems. “This is set to change as [standards such as] NABERS place value on operational performance, or WELL demands air quality to be measured in operation” reports one interviewee.

Systematic post-occupancy evaluations (POE) in a consistent format are still uncommon. This is often due to liability issues (i.e. architecture/engineering companies do not wish to be liable after handover) and confidentiality restrictions. “Doing proper POE is expensive and requires significant buy-in from tenants as well as the landlord. Most tenants just aren’t interested in letting strangers in to talk to their staff”.

What should researchers and scientists do to further integrate their findings, models and suggestions into the design practice?

Researchers and scientist should work collaboratively with the architecture and design team in order to clarify the implications of appropriate people modelling for building design. “We need a shift in the working practice”, from a workflow such as Figure 4 to a closer loop between design and modelling (Figure 5).

![Figure 5: Proposed workflow to be followed by architects and designers during the design process](image)

Work should be devoted to developing clear, user-friendly, bullet-proof workflows and robust methodologies, so that OB modelling may become more intelligible for the design team and become an actual design tool, as opposed to being purely relegated to the domain of specialists. One interviewee reported that “we want models that support our creative process”.

Such workflows would ideally contain visualizations and be backed by BPS engines. A change of culture in the perception of occupant (and especially OB) modelling is crucial to embark the clients onto occupant-centric visions and feedback practices.

Data, verification and validation of models “are essential”: increased access to open sourcing and expanded data repositories are needed. Sensors should be carefully and appropriately used to increase feedback between modelling and real world. “We need open protocols and consistent naming, but even then, data is power so we might be a long way away from having open repositories”.

As mentioned in Section 4.1, people are today considered at the offset of the design process when it comes to the occupant needs and experience that the design team has envisioned. Pedestrian modelling occurs throughout all the stages from Concept Design, Developed Design and Technical Design, in order to adequately inform passenger flow analysis, crowd management, and circulation design respectively. Similarly, OB modelling should be an integrated part of the whole design workflow, with models evolving and increasing their complexity and resolution as the design advances (Figure 66). The assessment of the robustness of building performance to variations in occupancy and behaviour should become well-established as a design concept and tool [39].

Conclusions

This paper explores the reasons behind the fact that the design implications of people modelling, with a particular focus on presence and behaviour modelling, are still poorly understood. The investigation is structured around three fundamental questions regarding current practices for people: modelling within the design workflow, possible barriers to a more appropriate representation of people and methods to remove such barriers. Results are reported from literature review and interviews.

Generally, architects and designers consider people primarily in terms of the recipients of the experience they envision through their design. Pedestrian modelling is a recognized tool to inform flow analysis and layout design, as well as to comply with safety regulations (e.g. fire-safety). In contrast, the modelling of presence and behaviour is perceived as a specialist domain and it hence not part of the typical design workflow. The most commonly used architecture tools do not encourage a further consideration of people within the design workflow: people modelling is troublesome and inefficient, and its benefits are poorly understood. Among the most important barriers to an appropriate consideration of people modelling within the design workflow are: Stakeholders, intended as lack of skills, understanding, vision and client interest; Software, both
in terms of robust models and methodologies, and their integration in architecture tools; and Feasibility factors such as the lack of support from standards and regulations, the unclear benefits and feedback, and the increased expenditure in terms of time and effort that appropriate modelling would imply. The key solution to improve the current status is increasing the level of communication and collaboration among design team, modelling team (or domain specialists), and clients.

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