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Untold Stories from the Field: a Novel Platform for Collecting Practical Learnings on Human-Building Interactions

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ABSTRACT

When implementing or studying building controls and interfaces in the field, researchers often witness first-hand human-building interactions from operators and occupants. While current comfort and occupant behavior models are able to explain some of these interactions, many fall under the fields of psychology, sociology and other humanities, which can be difficult for building technology researchers to interpret. Likewise, some causes of dissatisfaction, for example those linked to occupants' acceptance of automated solutions or interface usability, may not be captured by existing evaluation frameworks for indoor environmental quality. These behaviors remain either unmentioned or are brought up solely as anecdotes in the majority of building science research and are rarely explored in depth, despite their potential to critically impact the success of building controls and interfaces in real-world conditions. To address these gaps, an international collaborative effort was conducted as part of the IEA EBC Annex 79, to gather stories from research projects around the world. This paper presents a pilot study, which offers a new framework for story collection using an online collaborative platform for planning and brainstorming. Through a series of prompts designed to encourage storytelling, researchers were invited to share anecdotes of unexpected operator or occupant behaviors, and to reflect upon their experiences and others' stories. First, the anecdote collection

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framework is described, followed by an analysis of stories from the pilot study, which is based on an inductive qualitative approach. The disconnect between researchers' expectations and the reality of occupant behaviors was seemingly driven by factors that can be broadly grouped into three primary categories: (1) faults in building systems, (2) complexity of IEQ perceptions due to interpersonal variation and interplay between different IEQ factors; and (3) non-physical reasons for occupant dissatisfaction (e.g., due to their perceptions of the building systems' complexity and automation).

INTRODUCTION

Evidence from diverse building types across the world shows that buildings often fail to fulfill occupants' expectations in terms of indoor environmental quality (IEQ) and well-being, and as such, they are rarely operated in an energy-efficient way (Berry et al. 2014; Bordass, Leaman, and Ruyssevelt 2001; Pastore and Andersen 2019; van den Brom, Meijer, and Visscher 2017). Although there has been major progress in occupant behavior modeling in the past decade (Yan et al. 2017; 2015), research on this performance gap demonstrates the difficulty in creating reliable representations of occupant preferences and behaviors in building design and operation. IEQ perception depends on a range of contextual and psychological factors that can be difficult to measure, such as perceived control over the environment, habits, usability of interfaces, or availability of information (Andargie, Touchie, and O'Brien 2019; Brager and de Dear 1998; Castaldo et al. 2018). There is therefore a need to tackle the influence of non-measurable factors on occupant satisfaction, and consequently on their behavior.

An increasing interdisciplinary body of literature is recognizing the importance of these drivers of satisfaction and behavior, and has begun to integrate them into frameworks used in the engineering disciplines (Hong et al. 2017; D'Oca et al. 2017). Yet, because these behaviors are difficult to quantify and measure, and not yet integrated into most classical occupant behavior models, corresponding unexplained occupant behaviors may not be systematically reported in building science research outputs, or they may be simply mentioned as anecdotal evidence. These unreported findings from research projects around the world could constitute valuable evidence of non-measurable drivers of satisfaction and behavior, and contribute to bridging the real-life discrepancy between expected and actual user satisfaction.

The work reported in this article is the result of an international collaborative effort carried out as part of the IEA EBC Annex 79 (O'Brien et al. 2020). The aim was to collect evidence from researchers who directly witnessed occupant behaviors and resulting building interactions through a novel online platform, which was designed to encourage storytelling. Due to the complex nature of this research problem, an interdisciplinary qualitative research approach was selected. Interdisciplinary integration is defined as "the cognitive activity of critically evaluating and creatively combining ideas and knowledge to form a new whole..." (Repko 2008, p.344). Combining these varying disciplinary insights from multiple fields has enriched the overall outcomes of this research. The international team who conducted this research includes experts from the following fields: Energy Engineering, Building Engineering, Architecture, Industrial and Systems Engineering, Human Factors, Interior Design, Education, Construction Management, Civil Engineering, Urbanism, and Mechanical/HVAC Engineering.

By analyzing stories from the field through this interdisciplinary prism, the goal of this work is to reach a holistic understanding of the reasons behind real-life successes and failures of building controls and interfaces, and ultimately to inform the design and operation of future occupant-centric building systems and interfaces. The present paper reports the insights from a pilot study testing the developed method.

BACKGROUND

Energy performance gap and representations of occupant behavior

The building energy performance gap is defined as the gap between actual (or measured) and predicted (or simulated) energy performance (Pollard 2011). Identified causes of this performance gap include modeling errors, faults in the design and operation of building systems, and unexpected occupant behaviors (de Wilde 2014; van den Brom, Meijer, and Visscher 2017). Although, a recent comprehensive literature review by Mahdavi et al. (2021) claims that the role of occupants as significant contributors to the energy performance gap is not sufficiently substantiated by evidence. Others suggest that occupant behavior influences building performance (energy and comfort) through adaptive and non-adaptive behaviors (Hong et al. 2016). Energy-related adaptive actions include adjusting thermostats, opening/closing windows, turning lighting on/off, lowering the blinds. Non-adaptive behaviors include occupant operation of electrical equipment (i.e., plug loads), as well as building occupancy and movement through spaces (D'Oca, Hong, and Langevin 2018). A variety of models have been developed (Carlucci et al. 2020) to mimic these processes. However, a growing body of research points at inaccurate and simplistic assumptions made in the design and operational phases of buildings, showing that (i) current models of occupant interaction with their indoor environment are incomplete (Heydarian et al. 2020; Hong et al. 2017), and (ii) the existing knowledge is not fully translated into practice (D'Oca, Hong, and Langevin 2018; O'Brien et al. 2020). Several factors, reviewed below, are often noted for their impact on occupant behavior and satisfaction, and are at the same time poorly addressed in design practice.

Information and education. Providing occupants with information on building operation and control has positive effects on IEQ satisfaction (Bordass, Cohen, and Field 2004). Similarly, it has been shown that occupant education and engagement is an important factor for building performance, especially in high-performance or net zero energy buildings (Day and Gunderson 2015; van der Grijp et al. 2019). Building operators also play an important role in meeting occupant comfort goals while operating building efficiently, and they need proper tools and knowledge to do so (Baker and Hoyt 2016).

Perceived Control and Acceptance of Automation. Operating buildings based on occupant sensing and intelligent learning of their preferences is acknowledged as a promising solution to balance energy efficiency and comfort in buildings (Park et al. 2019). Yet, fully delegating indoor climate provision to an automated building system contains an inherent risk, as a large body of literature showed a relationship between occupants' IEQ satisfaction and their perceived control over the indoor conditions (Boerstra et al. 2013; Brager et al. 2004; Luo et al. 2014). It is important to distinguish which part of a building control system should be under direct occupant supervision and which should be hidden (Karjalainen 2013).

Human-building Interface. The next step is to design a suitable interface for this supervision. Usability and understanding of building interfaces are crucial for occupant–building interactions (Bordass and Leaman 1997; Karjalainen 2007, Heschong and Day 2021) in the context of building performance. The proliferation of connected systems and multimodal interfaces (e.g., wall mounted and phone-based thermostats) necessitates greater understanding of relative human and machine strengths (Fitts 1951), human information processing (Wickens 1992), human technology acceptance (Davis 1989), and usability (Norman 2013; Hartson and Pyla 2012).

Storytelling as a research method

To investigate these issues, many researchers have applied qualitative and/or quantitative data collection methods including questionnaires, structured interviews, focus groups and expert walk-throughs (Leaman, Stevenson, and Bordass 2010). Each of these methods has advantages (subjective data, benchmarking, etc.), but a common drawback is the 'intrusion' of the researcher in the discourse of the participants. To address this limitation, in exploratory research, narrative interviews allow the participants to tell their own stories in their own words. This method enables the collection of rich and detailed reports from participants on 'what has happened?' or 'what is happening?' (Lofland et al. 2006). Typically, a narrative includes a temporal ordering of events (beginning, middle and end) and goal directed actions. A narrative may be viewed as a reflection of a participants' mental model as a verbal representation of the environment or problem described (Johnson-Laird 1983). A study by Kempton (1986) employed interviews as an exploratory tool to establish two theories of thermostat use and users' mental models of their heating control. Here, the question might have been 'what happens when using your thermostat?' The users would either refer to a "*self-regulated device*" (feedback theory) or to a "*continuously varying flow of heat*" (valve theory). The present study builds on this method by using an online platform (www.miro.com) to gather researchers' narratives of occupant behaviors and resulting building interactions.

METHODOLOGY

This study utilized a qualitative research methodology. Qualitative methods allow researchers to gather comprehensive descriptions of particular issues or areas of interest. Qualitative research results are not meant to be generalizable to other conditions or sites; rather, they are used to provide a robust understanding of a very specific problem. For this study, we designed a unique tool to gather stories from other researchers surrounding occupant behaviors.

Data collection tool and participant recruitment

The online collaborative platform Miro was chosen to collect the stories. The board can be viewed through the following link: https://miro.com/app/board/o9J_knN8H4g=/. Stories were collected by asking participants to fill in the board by following a series of prompts:

- *"My story takes place in..."*- building-related information, such as number, type (e.g., office, residential, educational building) and location (e.g. city, country, continent);
- *"The technology or building system..."*- the technology or building system (e.g., ventilation system, connected thermostats, new control algorithms) in relation to the anecdote;
- *"Was this an existing system or did you implement it?"* - the research was not limited to new system implementations; both observational studies and interventions on existing systems were included;
- *"The goal with the technology/building system was to..."* - the description of the original aim or the expected outcome of the technology in the experiment/intervention/observation study;
- *"In real conditions, what happened was..."*- the description of the unexpected human-building interaction observed by the researcher, including details about how this information was gathered;
- *"Because..."* - researchers were asked to interpret the unexpected phenomenon based on available evidence, their experience in previous experiments, and their scientific background. This was a fundamental section of the board, since the researcher had to search for a synthesis between their roles as director and spectator of real life implementations, attempting to find a coherent and scientifically-based cause of the previously described unexpected interaction;
- *"What is this interpretation based on?..."* - this relates to the evidence based on which the researcher reached this interpretation (e.g., data collection, conversations, observations, personal experience);
- *"What we can learn from this story, and what should be done..."* - relying on researchers' expertise, fundamental lessons learned and best practice suggestions for future studies were proposed (e.g., about experimental design, interface usability, monitoring techniques).

For this first pilot study, experts from the IEA EBC Annex 79, who were interested in this activity, were invited to fill the board with stories based on their direct experiences (e.g., experiments in which they took part directly). The access to the board was provided by a web link to the Miro board. Since the board was created with the intention of constituting a collaborative space, participants could fill in the table with their own story (in an anonymous way), but also read the ones shared by colleagues. This feature, which could influence participants' storytelling, was intentional, since the aim was to encourage reflections by providing prompts from similar experiences. For this reason, before sharing the table, exemplary stories were provided as examples. The choice of targeting researchers instead of surveying occupants or building operators was also an intentional feature of this study. In fact, the aim of the work was to go beyond the collection of unexpected human-building interactions by asking researchers about their personal interpretation (based on their expertise) of the reasons behind implementations success or failure, as well as suggestions for best practices.

Data Analysis Process

When conducting inductive data analysis, researchers build patterns, themes, and overarching categories using a bottom-up approach. This inductive and iterative process allows the researchers to work back and forth between the data, the findings, the themes, other researchers' thoughts, and the data once again (Creswell 2009). Our interdisciplinary team scheduled recurring Zoom meetings bi-monthly over the course of several months to work through this inductive analysis of the data using the original Miro board that contained all of the participants' stories. The first phase of the inductive data analysis was conducted during a virtual workshop in which every participant identified relevant themes emerging in each story and reported them on sticky notes. All sticky notes were first placed aside each story without searching for any particular order. In a second stage, participants were able to arrange them and elaborate their personal framework of interpretation. Several individuals in the research team generated mind maps to document the way they were thinking about the data and processing connections between stories; the synthesis of these mind maps is illustrated further below in Fig. 2. This back and forth process was replicated, using several evolving Miro boards, moving virtual stickies around, and intense virtual conversations, until the research team had identified a comprehensive set of themes that adequately reflected findings from the written statements. The figure below illustrates this complex process, from the research question to the interpretation of the findings (see Fig. 1).

During the data analysis process, particular care was given to ensure the reliability and the validity of the findings. Reliability relates to the consistency of the methodological approach adopted throughout the analysis (Creswell 2009). Each of the team members assigned codes to all of the stories, compared each other's codes and discussed their interpretation together. Second, in order to ensure the validity or accuracy of the findings, several strategies were adopted. More weight was given to the themes that appeared in several stories. Moreover, the team members specifically tried to uncover and document their own biases linked to their background and previous experiences. The interpretation of the findings could then be interrogated in light of these different combined perspectives, with the aim of reaching a final output that was as unbiased as possible (Patton 2009). As a consequence, the final mind map (Fig. 2) is an attempt to show the complexity of the reasons behind perceptions and behaviors in buildings, rather than to draw simplifying conclusions.

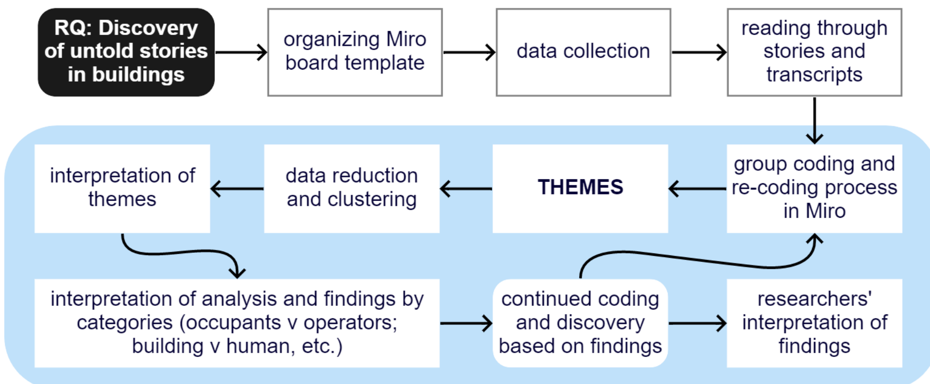

Figure 1 Diagram illustrating the methodological process. The blue area refers to the collaborative team process.

FINDINGS FROM THE PILOT STUDY

Collected stories

Annex 79 researchers collected eighteen stories for this pilot study. Most of them occurred in offices (10), one in an educational building and seven in residential buildings. Stories came from about ten countries (in three cases, the building location was not reported) and four continents: Europe (7), North America (6), South America (1) and Asia (1). Building performance data was not collected in detail, but the stories mentioned both typical systems and cases with advanced control systems or nearly zero energy buildings. Six cases described implementation of a new solution; the rest (12) were observations made in buildings with existing systems. Almost half of the stories (8) focused on ventilation systems (air supply or air velocity systems), another four focused on thermostats, and another three on more complex HVAC issues. Human interaction with lighting controls, energy feedback displays and sensors were represented by one story each.

The stories were told by researchers based on different methods. Four of the stories were indeed anecdotal cases coming from informal conversations or observations. Two of the stories were based on qualitative methods: (semi-structured) interviews or surveys while four were solely quantitative methods - measured data. However, half of the cases (9) were based on a mixed method approach, where both quantitative and qualitative research were performed.

Interestingly, only one story was presented as successful. Researchers implemented a new temperature control system in the existing building. The system learned occupant thermal preferences in their offices based on monitoring of occupant-building interaction. As a result, the system adapted to occupants' demand and also achieved energy savings. The remaining stories conveyed problems or unsuspected behaviors.

Insights from the stories

The mind map in Figure 2 showcases the major themes and connections uncovered during the collaborative working sessions. Using an inductive approach, we categorized the major themes from each story. Each circle's size represents the number of stories associated with that category, while the connecting lines represent the number of stories that are common between the connected categories. We chose to highlight the major connections in the graphic, but other connections did exist (two stories or less) that are not shown here. Because nearly all of the stories collected indicated some sort of failure of a technology (either existing or implemented), this mind map primarily tells a story of the challenges and failures related to building technologies. As we collect more stories, we expect to categorize and connect more themes, both positive and negative.

In the mind map, the most important topics and the strongest connections among them become clear. The main gaps observed are the frustration of researchers' expectations and the inability to understand or predict occupants' demands. The stories illustrated different reasons for such discrepancies between researchers' expectations and reality, which could be classified in three categories: (1) faults in the building systems, both because of inadequate functions and poor quality of the final product; (2) the complexity of IEQ perception due to interpersonal variation and the interplay between different IEQ dimensions; and (3) non-physical reasons for occupant dissatisfaction, linked to their perception of the building systems' complexity and automation, their previous habits and experiences, and their sometimes conflicting relationship with the researchers.

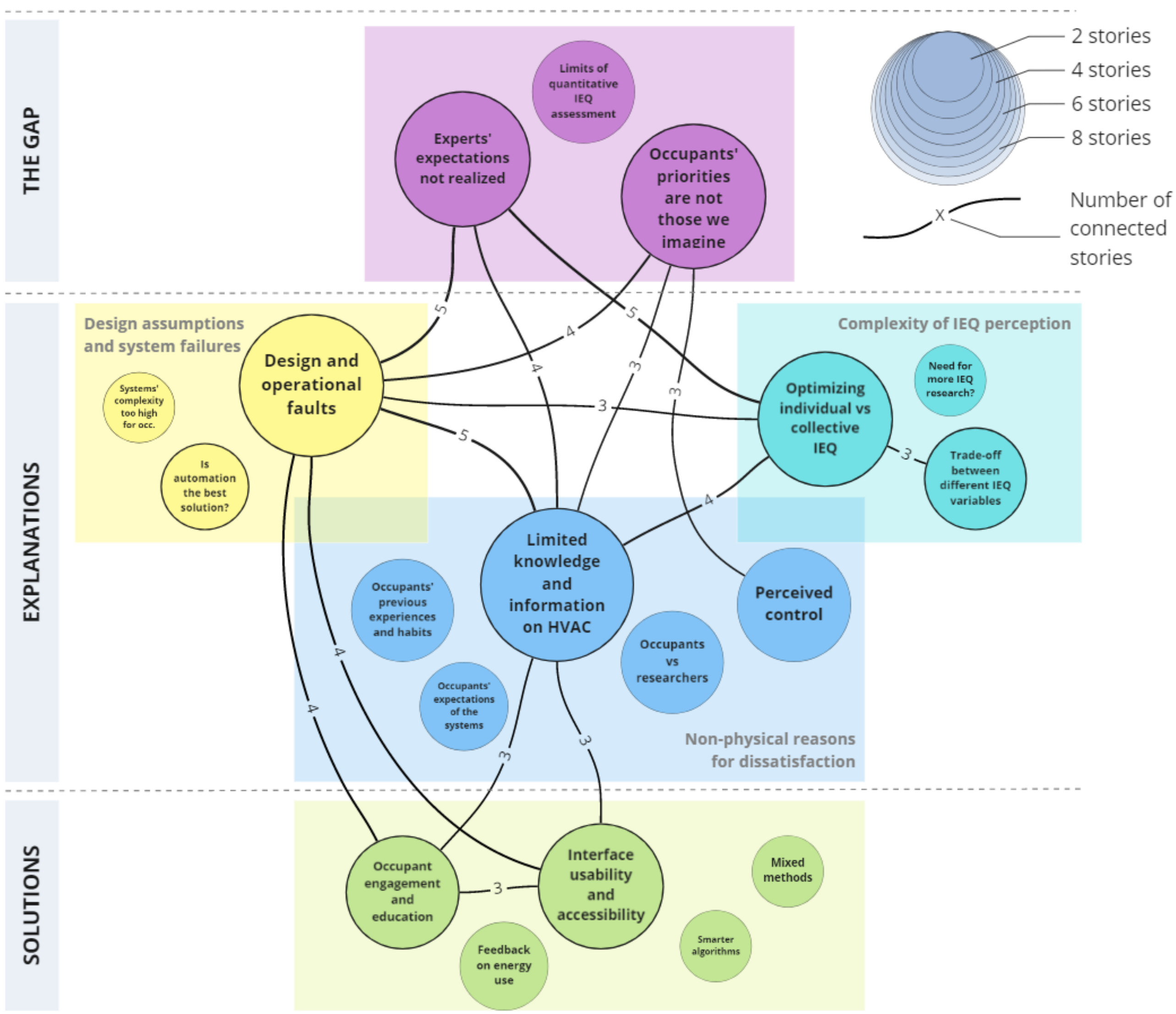

Figure 2 The mind map showcases the methodological process and emerging themes. Connections have only been drawn between themes if they were reflected in 3 or more stories.

The connection lines provide an added layer of insight between the themes. Among the gaps and their causes, the most recurrent connections are between researchers' expectations and design faults, optimal individual vs collective IEQ, followed by limited knowledge and information on HVAC. The connections between the stories are complex and varied, thus the best way to explore these connections is by highlighting some examples.

Connection: Experts' expectations not realized - Design and operational faults. In story #11, smart thermostats were implemented in a multi-unit residential building to reduce suite energy use by increasing the functionality of the interface. The occupants were observed to have frequent interactions with their thermostat (in one case over 400 times in a 4-month period) as well as unexpected window and door behaviors. After investigation, the researchers found that most of the room loads were provided by the pressurized corridor, lowering the thermostat's effectiveness. Control devices such as thermostats cannot provide effective comfort or energy savings when the building systems are not commissioned properly.

Connection: Occupants' priorities are not those we imagine – Perceived control. In story #13, desk fans were implemented to improve localized thermal comfort in an open-plan office. The occupants indicated that noise was a barrier to use them and typically only used the fans on their lowest settings. People's satisfaction with their air movement increased during this study, but thermal comfort was not significantly impacted. The occupants prioritized acoustic comfort for themselves and their neighbors, and the full potential benefits of perceived control over thermal comfort were not realized.

Connection: Occupants' priorities are not those we imagine - Limited knowledge and information on HVAC - Interface usability and accessibility. Story #7 investigated the use of thermostatic radiator valves in dwellings, designed to keep rooms at a constant temperature. Many residents were using the valves as an on/off device, which was not the intended use. Occupants seemed to value the reactivity of heating systems more than the possibility to achieve constant heat. The researcher who told the story speculated that providing occupants with information and a more intuitive interface design could promote a more energy-efficient use of these devices.

The solutions suggested by storytellers included boosting the interface usability and accessibility, and engaging and educating occupants on how the system works. This means both the faults and the solutions are shared between the researchers, designers and users. Comparing the issue of expectations against proposed solutions, we perceive that researchers have to develop multiple capacities. When evaluating occupants' comfort, they need to understand how to design a system and its interface; how to engage users; and how to make an educational campaign. For this purpose, new skills are needed, including knowledge about the most effective strategies, which may go beyond researchers' field of study or training.

Different perspectives on the same data

As previously described, the iterative process that led to the development of the final mind map was characterized by several moments of individual and collective work. Inductive analysis, in particular, was conducted partly singularly, partly in small groups and partly in plenary sessions. It is interesting to note the variability of coding approaches and visualizations that different members of the group proposed. During the first coding stage, a variety of approaches could be recognized, e.g., some participants selected keywords contained in the stories, others summarized a relevant theme in a short sentence, etc. In the second stage, where the sticky notes containing the codes were organized individually by each participant, a variety of representations could be recognized (e.g., mind maps, tables and flow-charts). Some researchers chose flow-chart schematizations, in an effort to recognize the presence of causal relationships, from the recognition of the problem to its collocation within certain boundaries and the identification of possible solutions (Lloyd and Solak 2003). The organization of data in tables was also a useful tool to progressively relate different stories and recognize patterns. Finally, mind maps, as 'visual, non-linear representations of ideas and their relationships,' were chosen by other researchers as they allowed a comprehensive representation of the complex connections between items, also offering innovative ways to look at underlying unexpected relations (Biktimirov and Nilson 2006). The variability of representations allowed the team to uncover different ways of processing the data. All the representations and analyses of the dataset offered tangible sources for group discussions, such that the final version of the visual framework can be considered as an integration of all the previous approaches (Franco 2013; van Beek et al. 2020).

Some interesting observations became evident through the analysis of the stories. Firstly, the original stories were told from a singular subjective perspective, that of an individual narrator, which in some cases was an occupant and in others an observing researcher. The content of each story was then largely based on discrepancies between the expectations or knowledge of the main character in the story and the reality in the building. The subjectivity of a story became obvious in one example where occupants had an individual setpoint temperature control in each office, but were not using it, as it did not seem to have much effect. From an occupant perspective, there was a discrepancy between expected and real response of the system. A facility manager however, who was aware that several offices were zoned together, sharing VAV ventilation (effectively preventing individual control), might have expected this behavior. Second, the interpretation of these stories by the authors of this paper contextualised the individual stories, in this case by grouping them according to the cause of the discrepancy between expectation and reality. In contextualising the subjective individual stories, the authors of this paper added an additional perspective on the subjective narrative. As this contextualisation was a collaborative process, more perspectives were considered than would have been possible with a single researcher conducting this process.

DISCUSSION AND CONCLUSIONS

This pilot study, which collected eighteen stories from research projects around the world, enabled our international and interdisciplinary team to identify three main reasons for the gap between expected and actual occupant behaviors and satisfaction in the studied buildings, to draw connections between them, and to gather researchers' proposed solutions to these issues. The work presented in this article is a preliminary study, and now that the process and method have evolved, a second phase of data collection and semi-structured interviews will follow. This method has potential to uncover aspects of occupant behavior in buildings that are rarely studied in depth: indeed, some of the collected stories had never been reported in research articles, but they helped reveal the bigger picture of occupant interactions with building systems.

A key observation from this research was the importance of multiple perspectives when researching human-building interactions. Occupants' perspectives and priorities were not always understood by the researchers, building designers or operators, who had their own view and metrics of good building operation. The researchers who told the stories, and those who analyzed them, introduced a next level of subjectivity and new perspectives on the findings. Each perspective can only offer a part of the truth, and multiple perspectives together reveal a bigger picture. Individual stories highlighted the range of diversity of perspectives, whereas the contextualisation offered deeper insights into the system dynamics of human-building interaction. This research suggests that relying on a single reading lens for building design and operation, but also in building research, contributes to the gap between expected and real occupant satisfaction in buildings. Designing truly occupant-centric buildings may require acknowledging the different players' biases and gathering more knowledge on occupants' perceptions, needs and preferences directly from the field, both in qualitative and quantitative forms.

The data collection method also showed some limitations. The intention of the project, to focus on stories, implied a certain bias towards reporting failures as opposed to success stories. As mentioned above, we observed that the stories tended to focus on discrepancies between the expectations or knowledge of the main character in the story and the reality in the building. It appears that the use of the term "story" indicates that the bigger this discrepancy, the more of a story there is to tell, whereas a match of expectations and reality (=success) might be more associated with a "report." This is perhaps related to the expectation that the research will confirm the hypothesis that underlies it, and that a negative result is not well regarded. In general, publications highlight the successes of the research as its greatest contribution. However, for the development of knowledge, both positive and negative results are important for future research. In this sense, the proposed tool fulfilled the role of providing an environment in which the researchers felt comfortable to share weaknesses in their research. This process offered the possibility of discussing them and identifying ways to improve research procedures related to occupant behavior. The identification of solutions will however require a more in-depth analysis of the stories to fully understand their context in more detail. Furthermore, as other stories are added to the platform, it is expected that recurring points change and the relationships between them expand and are redefined. This iterative process will be important for discovering new connections and verifying others. As data collection continues, a point for improvement is to promote the board as a space for exchange and make its objective clearer so that it may also gather positive stories and knowledge that respondents want to pass on.

Given the valuable insights from this pilot study, we plan to promote this story-gathering platform within the IEA EBC Annex 79, related conferences, and the broader academic community. We aim to gather approximately 100 additional stories from researchers. Using the contributions, we will expand the analysis described in this paper and further enrich our findings with semi-structured interviews and focus groups. The end goal of this research is to create a comprehensive guide for the implementation and operation of building technology. We will identify the root causes and target sources of challenges, such as system commissioning, interface design, HVAC complexity, and occupant education campaigns. By focusing on the users of buildings, we believe continued efforts on this research will address a critical gap in the building industry.

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