“No powers, man!”: A Student Perspective on Designing University Smart Building Interactions

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ABSTRACT
Smart buildings offer an opportunity for better performance and enhanced experience by contextualising services and interactions to the needs and practices of occupants. Yet, this vision is limited by established approaches to building management, delivered top-down through professional facilities management teams, opening up an interaction-gap between occupants and the spaces they inhabit. To address the challenge of how smart buildings might be more inclusively managed, we present the results of a qualitative study with student occupants of a smart building, with design workshops including building walks and speculative futuring. We develop new understandings of how student occupants conceptualise and evaluate spaces as they experience them, and of how building management practices might evolve with new sociotechnical systems that better leverage occupant agency. Our findings point to important directions for HCI research in this nascent area, including the need for HBI (Human-Building Interaction) design to challenge entrenched roles in building management.

Author Keywords
Human-Building Interaction; HBI; Sustainability; Sustainable HCI; Speculative Design; Walking; Living Lab

CCS Concepts
• **Human-centered computing~Empirical studies in HCI**

INTRODUCTION
A growing Human-Building Interaction (HBI) community in HCI is acknowledging that the increased integration of IoT and sensing in buildings will have a significant impact on how we experience them and, as such, they *“should be designed and nurtured in a dialogue with their users at the individual as well as social levels”* [1]. A body of HCI literature has focused on automation, on understanding and designing interactions with intelligent, automated systems (e.g., [33,59]), and on understanding the role of the building occupant in this. But, at a recent CHI workshop on HBI, one of the pressing questions that emerged for the community was “*How can smart environments embrace inhabitants’ agency?*” [2]. We specifically take up and address this question in this paper.

There is an important and recognised need in the construction industry for new ways to evaluate buildings. Office buildings are designed, built, and evaluated according to criteria determined by the construction industry and a relatively small set of stakeholders involved in the procurement process. Although some consultation is often undertaken when commissioning a building project, methods for assessing and evaluating project success are often scoped around the performance of building fabric and systems, with an assumption that the needs of occupants will be addressed if this is functioning correctly. The longer-term evaluation of buildings is a neglected area, but one which can have a large impact on occupant health and wellbeing, and on the life-cycle costs of the building, which are significantly higher than construction costs. Smart buildings and increased occupant agency in the management process offer new opportunities for better capturing and negotiating building performance and use over the extended life cycle of a building, and for designing interactions to integrate this into the normal habitation of the building.

This paper presents an enquiry into the scope for designing new building management practices within the university context. We explore how HBI might leverage the expertise of student occupants in an ongoing conversation, allowing them to negotiate the terms under which a building should be evaluated (and re-evaluated). To investigate this, design workshops were carried out with student occupants of a smart building. The study was designed around how engagement might be fostered in the management process, with the aim of producing understandings to guide the design of future smart building interactions. To address this, we specifically ask:

> **RQ1**: How do student occupants conceptualise space within the building?
>
> **RQ2**: What are students’ existing perceptions and expectations of HBI and facilities management, and what is the role of the student occupant in these?
>
> **RQ3**: How can we design interactions that foster agency and participation for students in their everyday experiences of university smart buildings?

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In addressing these questions, we develop new understandings for HBI by contributing an account of the student perspective for design, as well as new understandings of how student occupants conceptualise space, and how they perceive their role and agency in future smart environments. While Hasselqvist et al [28] advocate for combining different stakeholder perspectives and supporting shared responsibility between them, in this work we take a deep dive into the perspective of students. Other stakeholders are important to understand for a holistic account, but have different practices, experiences and expectations beyond the scope of this paper. As such, our findings relate to the social fabric of student experience within a smart building, giving an important perspective for appropriate and effective building interaction design within the University context.

RELATED LITERATURE

HCI and Building Management

HCI and related communities have concerned themselves with understanding and evaluating indoor environments and how people use them. Some of these have focused more on collecting and understanding data. Verma et al. [54] report on the use of a pervasive sensing system to understand how space is used in buildings. Mitchell Finnigan et al. [42] also considered the role of sensors in the auditing practices of building managers. In their case, they were concerned with the design a wireless sensor toolkit to support auditing practices for evaluating building performance and ensuring standards compliance. Related to this, Mauriello et al. [39] investigated roles for thermography in building energy auditing and how interaction design might enhance this.

Complaints are another mechanism by which a facilities manager will learn that the occupants of their building are unsatisfied with the environment which is provided to them. Previous work in HCI has outlined the issues inherent in this as an engagement method [16]. Yet, there is surprisingly little cross-over or engagement within HBI with HCI work which addresses hegemony or power imbalances [36], or feminist notions of agency, equity and empowerment [4]. Clear et al. [16,17] focus on occupant participation in building evaluation and management. They investigate the role of environmental data as a mechanism to mediate interactions between building managers and occupants, and suggest ways that it can leveraged for more inclusive and bottom-up building management [16]. In their work on ThermoKiosk [17], a device designed for conducting occupant surveys of thermal comfort and visualising the results to them, they highlight an important role for occupant dialogue and agency to resolve tensions around shared comfort. Building on this work, we are concerned with how occupant perspectives can be included in negotiations about how buildings and their spaces are managed and evaluated. Conceptually, we acknowledge that building occupants are engaged in the continuous creation [40] and appropriation [21] of space, and so we take a step back and ask how occupants experience and evaluate space, and how they conceive of their role within the management and adaptation of it. In this way, we aim to understand how design can support occupants in playing a role in building management, but also in determining the metrics by which spaces should be evaluated.

Smart Homes

In the domestic context, Desjardins et al. [20] highlight the smart home genre's central questions: "What is a smart home?" and "How do people live in, maintain, and install a smart home?" Living lab approaches in investigating these e.g. [32,49] allow insights into peoples' lived experience in smart homes. The genre often centres on home automation, positioned as addressing sustainability by reducing resource-use e.g. [6]. Strengers [51] criticises this as places responsibility on the individual consumer, potentially hindering progress towards a low-carbon future. Brush [14] found that applications included heating automation, but also lighting, security and media systems. Mennicken et al. [41] criticise the use of "smart" as a marketing term for automation, instead defining the smart home as increasing comfort, but also enabling functionality which would be impossible without computing technologies. They suggest that "*smart homes will collaborate with their inhabitants instead of only being controlled by them*." We take up and extend this provocation to non-domestic buildings: it is not enough for a building to employ automation alone in order to earn the moniker "smart."

Designing for Future Scenarios

In order to understand and inform future interaction design trajectories, a growing body of literature investigates perceptions towards speculative technology within a future context that does not yet exist. Various approaches are used to illustrate these technologies and future contexts for users, such as physical prototypes and simulation [34,38,45], videos [11], and animated sketches [48]. Ambiguity is an important resource [26] for such design processes in order to leave space for interpretation and for "*critical and creative dialogue*" [11]. Vines [55] discusses provocation and humour as design resources, leveraging critique as "a valuable resource for generating new ideas and inspiration". Rodden et al. [48] used animated sketches to help consider interaction design within future energy systems based on software agents, as sketches can be interpreted in ways that a finished prototype could not. Briggs et al. [11] draw on ambiguity more explicitly by developing videos depicting interaction scenarios but with the technology missing. In our work, we allow for ambiguity by using narratives around a set of diegetic artefacts [23] to depict speculative scenarios of future building management. Like Broms et al. [12], we champion the power of stories told through such artefacts to re-imagine everyday life and critically examine social norms. We also intend them to be provocative [5,55] to stimulate reflection and discussion, as inspiration for a design exercise. For this reason, we expressed them as complete (if not implemented), illustrated "solutions".

METHODS AND PARTICIPANTS

A newly constructed (2017) smart university building in the UK, intended to be a living lab for sustainability research, was the site of investigation for this work. The building is characterised as "smart" because of its highly granular data collection system used by facilities managers to aid in problem diagnosis and to monitor energy efficiency, coupled with a BMS (Building Management System) which adjusts comfort functions, such as temperature and lighting, accordingly. Its occupants are diverse: office workers (academic and admin staff) and students. The north wing of the building is designated as staff workspace, and the west wing is allocated as teaching and learning spaces, including seminar rooms, a lecture theatre, and computer clusters. A central atrium is enclosed by thoroughfares and ad-hoc meeting and collaboration spaces which overlook it.

We recruited student occupants (5F, 11M) for two design workshops by advertising through a departmental mailing list. The workshops aimed to understand how participants conceptualise spaces within the building, and to engage them in the speculative design of smart building interactions where they have greater agency in the management, operation, and adaptation of the building. The workshops were 2½ hours in length and consisted of two main sections: a building walk and a design task. The building walks were inspired by walking methodologies used previously in the social sciences and in HCI to explore peoples' relationships with place [11,18,19] The second half of these workshops made use of speculative design [23] to prompt reflection and discussion on a set of abstract scenarios of future buildings management, and to serve as inspiration for a free design exercise undertaken in the final section of the workshop. With these tasks we sought to bring out the social and cultural assumptions which underpin both building interactions and management, and the development of technology, respectively. Participants were offered a £30 voucher for their participation in the workshop. Workshop activities were run in 3 groups of 3 students (9 participants per workshop total) with a group of two in the second workshop as one participant did not attend. Workshops were undertaken consecutively on a Wednesday afternoon (traditionally a gap in the student teaching schedule) at the start of the summer term. Written informed consent was given by participants and ethical approval for the study was granted by the institutional review board of the lead author.

Workshops

The workshops were structured broadly into two halves: the first half allowing students to explore the building and relate accounts of their experiences and perceptions of space; the second half drawing on those experiences to critique a set of diegetic artefacts and produce designs for future ways to address their perceived shortcomings of the building.

Building walks

Participant groups were first presented with a *blueprint flip-book* containing floor-plans of the building and asked to annotate them: for example, with routes through the building; where they spend time; the resources they use in those spaces; the people they interact with; and issues they may have encountered. They were then asked to use their blueprint book to plan a route around the building to visit the spaces they had discussed. Participant groups undertook the building walks they had designed unaccompanied by a researcher and were given pre-prepared questions cards to prompt discussion. These included prompts like "What's the purpose of this space– and what do people *really* use it for?", and "Who's in charge in this space?" Participants carried an audio recorder to capture the conversations they had during the walk and were given a Polaroid instant camera to capture snapshots to tell the story of their journey around the building during a follow-up feedback session. Building walks lasted between 30 and 40 minutes. Following the walk, students were asked to prepare a poster telling the story of their journey around the building, which they then presented to the other two groups and the researcher.

Speculative Design

The second half, following **RQ3**, focused on developing understandings from the walks into questions about what the building might look like in future, and what "smart" might mean for this. The speculative design task explored how student occupants might view technology, resources, and data as part of the building "fabric" and how they conceive of ideas which would change it, grounding this in their experiences of the building through the walks. Occupants were presented with a set of three illustrated scenarios of fictional future building management technologies, which we refer to as "diegetic artefacts" following Dunne & Raby [23]. These are distinct from design fiction [7] in that they focused on the technology, rather than the narrative supporting their position in the social fabric of the smart building, as we wanted students to discuss and imagine the wider context for themselves. Ambe et al. [3] assert that researchers should include user narratives in the design of fictions, and as such we drew on formative interviews with building managers to inform the design of our artefacts. Though these were designed by the lead researcher, rather than co-designed with participants, they drew on the themes from this guiding research which were presented in a workshop paper at CHI 2018 [44].

Participants were asked to critique these artefacts: they were conversation starters, used to situate the technology ideas within the building space, and to contrast student priorities with the points raised by management in the pilot interview study. Following Broms et al. [12], the designs (e.g. **A3** illustrated in **Figure 1**) were not intended to be serious solutions to problems, but were put forward as provocations [55] to support participants' critical examination of their norms of engagement with the building in daily life. Despite being imagined technologies, they are situated in the real context of the building: the ways in which they interact with this context, as imagined in this exercise, were interesting to us. The briefing sheets on these imagined artefacts included a description of the artefact and an illustrative scenario of

how participants might interact with it, and are included as supplementary material in the ACM Digital Library.

The first involved an autonomous intelligent agent for the building and its management, manifested as a Twitter-based online persona called SpaceBot (**A1**), previously published as a late-breaking work poster [43] at CHI. SpaceBot is an anthropomorphic representation of the building, curious about how people are experiencing it and in developing better understandings of what its sensor data means in terms of occupant experience. It could ask questions around *how people are*, what they *do or do not like*, and what would they like to *change or keep the same*. It tries to engage people in dialogue with others by asking their opinion on others' comments (e.g. by re-tweeting), and how people interpret data points that the building captures.

The second diegetic artefact, Questie (**A2**) draws on management desire to understand how student occupants perceive and engage with the space. It is a top-down solution for gathering ongoing feedback, which can help managers to figure out if there is a problem before it gets bad enough to prompt a complaint. The physical element of this design is a situated Q&A kiosk. Building managers assign questions to be asked of building occupants, or investigative tasks for them to perform (for example, "how many people are using this space right now?"). when a building occupant walks past Questie, it prints a question or task. The receipt is then scanned in the "returns" slot, and the person can bump their smartcard on the reader to collect points that can be exchanged in the cafe for food and drink.

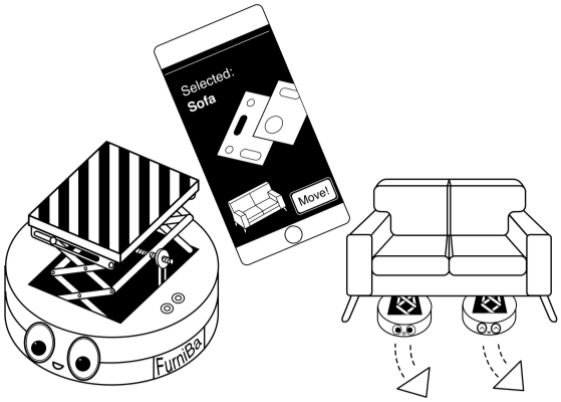

Figure 1: Concept illustration of the "FurniBa" artefact (A3).

The final artefact (**A3**) is *FurniBa,* a solution which allows bottom-up reconfiguration of furniture resources within a space. FurniBa works like a robotic hoover with a powerful lifting jack on its back. It can be called out, via mobile app, to reconfigure the space by moving furniture around. This diegetic artefact was intentionally silly [8,55], a reaction to solutionist design intended to probe students' thoughts on furniture location and use around the building, and inter-occupant negotiation in the control and management of this.

Groups were asked to read all three scenarios, then were assigned one to discuss in more detail and critique using a set of questions provided by the researcher e.g. "Where would this be useful?", "Who is the user? And what do they care about?", "How would you change the design?", and "How does it get broken?" Discussions of how they might change the building space, and where they might be effective, ineffective, or disruptive led to a final free design exercise where participants ideated and presented their own interventions.

Data and Analysis

The workshop exercises were audio recorded and transcribed. The workshops produced a heterogeneous data set comprised of these transcripts, annotated blueprint flipbooks, posters displaying Polaroid photos taken on walks, and participants' design concepts. The thematic analysis of this data corpus was bottom-up, involving iterative open coding of the workshop transcripts: other resources were indexed as they, or the locations they represent, were mentioned. 906 codes were used to label facets of HBI present in sentences, examples including "Comfort", "Responsibility" and "Ownership". The two authors iteratively affinity diagrammed these codes to produce three top-level themes from the walks data, and a further three from the speculative design data, with points of disagreement negotiated by revisiting the transcripts. The purpose of our analysis was to understand common themes from our participants relating to what HBI is (now and in the future) and how they experience it.

FINDINGS

Participants undertook the building walk and the design exercises in groups. We use pseudonyms to represent each participant and the group they were part of: *S1G3* indicates student S1 from group 3. Our findings are presented in two main sections covering first the situated experiences of human-building interactions, followed by the broader socio-organisational context of these.

Situated Experiences of HBI

Our investigation of **RQ1** led to findings on how students experience spaces in the building, and how they navigate them in terms of access permissions, social hierarchies, and institutional roles. In this section, we describe new understandings of how occupant-management interactions might be designed within the framework of participants' situated experiences with and within the smart building.

Securing Space: The Everyday Practices of Nomadic Student-Workers

Students in our study were nomadic workers: they had no assigned desk and were required to move around the building to find a workspace. A unique set of practices and building interactions formed around this kind of occupancy, mainly to do with locating workspaces of optimal quality. We find that space requirements are complex and involve a combination of factors broadly aligned across four categories: comfort, equipment needs, social needs, and spatial constraints.

Comfort needs include thermal comfort, ambient lighting, noise, and distractions: "*I'm quite particular about where I*

sit, I like a certain amount of light, I like temperature, I don't want my room way too busy…" (S3G4). Equipment needs are factors such as computer and lab equipment that may be required for some tasks. Social needs include group work: for example, sitting together was deemed desirable, but difficult given the high occupancy of computer workstations: "*if you were with three friends you couldn't sit together, you'd be separated*" (S1G1). Finally, spatial constraints include issues such as resource contention (e.g. rooms being full), access, and the building closing overnight: "*the building wasn't [open] 24 hours[-a-day] so I was there at like 7am, and then couldn't get in, 'cos it's staff only"* (S2G3). It was not always possible to fulfil all these constraints, so some factors had to be prioritised over others: "*There's no natural light, you have no idea of time. The air con's not particularly great. [But] it means you can concentrate if it's really busy downstairs…*" (S2G1). Such priorities vary depending on the task and the individual. For example, participants might turn down a space which would satisfy comfort requirements but wouldn't allow students to sit together for group work.

Participants saw value in a booking system for securing a space to work as this eliminated any compromises that might have to be made. Further, where it was unclear whether students had permission to use spaces within the building, booking supplied a mechanism for reserving the *right* to be there, reducing the risk of being 'kicked out:' *"... you can book some computers in there in case you end up getting kicked out of the labs […] because of other people's practicals!"* (S2G6). Only some rooms were bookable by taught students, with many being reserved for use by staff: "*unlike the upstairs meeting spaces […] there isn't an obvious booking system in play.*" (S1G2), and participants felt the system could be improved to open-up more of the building for their use. Even with the existing booking system, finding a workspace often occurred 'on demand'.

Concerns over finding suitable space were reflected in the free design task. Better information provision was one approach considered by G4, making reference to a technology already used in other campus buildings: "*it tells you if it's busy […] so it will be red at peak times […] for the library and the gym*" (S1G4). Other groups of participants produced similar designs but focusing on automating requirements management. For example, G1 designed an app that "*best places you in the building for happiness and based on your needs, and then it's also able to improve its recommendations to you…"* (S1G1). A combined recommender system and feedback tool, G1's app was envisioned to provide recommendations based on requirements, and improve those recommendations based on feedback: "*Once you've finished in a space you'll rate how good it is, and that will let the system build up this engine […] to recommend you better places…"* (S1G1). While these designs provided technological solutions to improving the efficiency of the existing space, the impossible reality of matching everyone's requirements was recognised. In this case, the fall-back would be to rely on existing processes of negotiation with staff: "*it would need to feed that back to the Uni, like, 'you cannot fulfil this requirement"* (S1G3).

Patterns such as commonly busy times do occur and could be captured to improve HBI. But our findings have also illustrated important qualities of student practices to consider in new HBIs: the nomadic nature of student habitancy, where work is often done in groups and finding an appropriate workspace involves trying to satisfy complex requirements. Booking systems might be better designed for this, but like other student practices [15] there is an element of spontaneity to these (when, where, and with whom) that makes them difficult to plan far in advance.

Negotiating Shared Spaces: 'Structured vs Deliberative' and 'Formal vs Informal' Mechanisms

In our data we saw various ways in which building interactions to do with changing the space were approached. Structured interactions (e.g. decision by consensus) were process-based compared to the more *ad lib* deliberative ones. And, formal interactions were operationalised through building managers or other staff in authority, compared to the informal interactions managed by occupants themselves.

Thermal comfort was experienced differently by individuals and was often contested. Consequently, participants felt that an informal or deliberative approach to addressing it would be inappropriate: "*… and you're like the only person constantly saying, 'it's too warm' and everyone just gives you death stares every time you tweet! ((laughter))*" (S1G1). A more suitable approach might be to offer a structured voting mechanism to agree on changes: *S1:* "*How would you change the design…?" S3: "Voting system!*" (S1,3 G4). One participant drew on past experience to support this: "*I've never been in an office where everyone's agreed on the aircon temperature so having a consensus algorithm that was like 'actually 78% of people said it should be colder' would be good.*" In investigating more agency and a greater role for students in building management (RQ3), **A3** focused on furniture as one facet of the building which might be reconfigured on-the-fly by occupants. Participants found it difficult to understand how this might work in practice, possibly as this is strongly tied to social roles and students' distrust in their peers to act responsibly: *S1:* "*This needs to be used responsibly with staff, like IT or lecturers, because this in the hands of a student, they will–" S3: "Mm, it won't end well. It will last a week or so but that's pretty much it*." (S1,3 G3) Yet, participants suggested that a consensus on furniture could indeed be reached: "*I can't actually think of many scenarios where people wouldn't just move it once and then that is in the optimum place for everyone*." (S1G1)

Pointing to the limitations of consensus-based decision-making, another participant pointed out the difficulty in reaching satisfactory decisions: "*… you can have a voting system […] but with many things it would be 50-50!*" (S3G1) While resolving conflicts was important to participants, it was recognised that sometimes a structured process might

not be sufficient. In another example, not knowing that changing a shared space might negatively affect others was a barrier to interaction: "*how do I know if I move the sofa [that] no one yells at me?!"* (S3G3). These examples might suggest the need for more deliberative approaches; however, participants leaned towards more formal processes of policy and management for resolving them. It was agreed that free reconfiguration could be problematic, and that perhaps there should be limits to what can be moved around: "*It would cause chaos in the area, like, in the building because it might move stuff that's necessary in one place actually.*" (S2G6). Participants preferred modes of reconfiguration closer to existing methods, e.g. via formal negotiation with staff, but it is likely that this is influenced by their familiarity to them.

Yet, more reactive and reconfigurable spaces were not an alien scenario. An existing concept discussed was the use of room dividers to break up a space. Participants envisaged the use of these in practical classes, solving the problem of being 'kicked out': *"when people have a practical and it's a small module, you […] section off the bit that you need for the module and the rest is free for other people"* (S2G5). This could be viewed as addressing a problem with the design of the building (i.e. holding classes in a large shared space) on which a more participatory management process might facilitate adaptation.

By considering agency and participation for occupants in interactions to do with changing and managing space, we see that it is useful to consider suitability across two dimensions: structured vs deliberative and formal vs informal. These categories serve as a useful tool in thinking about how traditional, centralised forms of buildings management might change in future HBIs to allow for more participatory forms of space management.

How Opaque Space Rules Lead to Unclear Affordances

Participants formed mental models about what spaces were for and their permission to use occupy and use them. Their mental models of these rules in turn informed use of the building. Where spatial rules were unclear, this negatively impacted students' ability to perceive spatial affordances.

Participants understood that their role as students affected what spaces they could use in the building, though often the access permissions for a space were unclear. A novel HBI arose relating to this: the use of student smartcards as a proxy for determining permission to use a space. *S1: "Are we allowed in?" S3: "Has anyone got a student card? ((card reader beeps)) That's a no! (laughs)" S1: "Ah, once again it beeped, sounding good, and didn't let us in!*" (S1,3G2). Participants discussed how it was unclear if they were allowed to use a given space or resources located in it, though it was assumed that if they could access a given space with their smartcard, they had permission to use it. The bike store is one example which students encountered on their walks, where postgraduates had smartcard access affording the storage of bikes, yet undergraduate students did not: *S2: "I don't think the [bike store]– the undergrads don't have access […]" S3: "They're too oppressed!" S1: "No powers, man!"* (S1,2,3 G1). Yet, students discovered through exploration that space access was actually more permissive than they had assumed: "*I'm seeing that my card actually opens more doors than I thought of it? And all these doors […] give you […] the wrong impression: that you are not allowed…"* (S1G3). Although for the walking exercise we did not expect participants to explore areas of the building which they would not normally use, some groups took the opportunity to do so.

Another heuristic for determining affordances was the known or implied purpose of a space. While, for some areas, participants had no knowledge of what goes on inside: "*Yeah, so, sort of general research, um– about… um… research about things. Yeah we're not actually sure exactly what goes on there.*" (S2G5), the perception that the space was for 'research' implied that an undergraduate student would not be permitted to use it. Another group complained about the lack of clarity on permission to use whiteboards located in a corridor space: "*These whiteboards. What's the deal with them? 'Cos a lot of times people just write random stuff on it? […] like– it'd be nice if we get told that we can do that?"* (S1G2). Although the affordances of the whiteboard were well understood (writing, erasing, etc), its location in a thoroughfare muddied the social permissibility of using it, resulting in an unclear spatial rule.

While some spaces have limited affordances in that they are physically inaccessible, there are also social barriers to interactions. G3 took a photo jokingly comparing the staircase from the 4th floor to "*Mount Olympus*", the seat of the Greek gods, and discussed how the top two floors of the building *felt* off-limits to them: "*I get a kind of, a sense of intimidation, because, you know, that's where most of the lecturers and PhD students reside, and there isn't many rooms for us to access up there. So, I don't actually frequent that floor. So, what I would say is, that when I look up those stairs, I see an inaccessible floor.*" (S3G4). The floor was not inaccessible in terms of the building's access rules. Yet, participants perceived its affordances according to the socio-physical design of the building, giving the impression that it was off-limits.

Perceived affordances are therefore impacted by understandings of space and how these are communicated. Gaver [25] points out that culture and experience highlight certain affordances. We found that spatial affordances are also defined and perceived according to the social hierarchy of the organisation. For example, a smartcard-locked door might afford access to research staff, but not to undergraduate students (Gaver defines this as complementarity of action). Yet, our student participants also understood space rules as conditional, reliant on social factors which had to be determined before they were *allowed* to use a given space or resource within it. Although S1 jokes "*no powers, man!*", spatial affordances are influenced by and intertwined with the organisation's social hierarchy, which is

reproduced and reinforced by the design of HBIs. Acknowledging this can enable better building interaction design for students' mental models and help pursue intended building design outcomes, such as satisfied and included occupants and fostering community and ownership.

Socio-organisational Considerations for HBI

Findings curated in this section illustrate the relationship between a smart building's socio-organisational context and HBI, and how an understanding of this context is essential to sensitively and appropriately design for its occupants.

Mediation is Necessary in Shared Buildings: but Occupants Need to be Better Involved

Interaction with management in our case-study building is funnelled through complaints to building managers. This service-oriented interaction modality has advantages, but also disconnects building users from their environment and reduces their agency in the space.

Two of the diegetic artefacts, **A1** and **A2**, were imagined systems for gathering feedback on an ongoing basis instead of waiting for complaints, as we wanted to explore alternatives to this management process. Discussions of these brought up questions of occupant agency and control. While we imagined new mechanisms for communication between management and occupants might increase a sense of agency, providing feedback and information without a tangible response had a negative impact on perceptions of control: "*… it would be good if you could like not just get the information but request a change*" (S3G4). This relates to experiences of the complaints process. Conversations relating to broken computers and thermal discomfort in particular, came up often: e.g. discussing overcrowding and overheating problems in a lecture theatre: "*That lecture room is the worst thing I have ever been in*" (S2G1). While participants emphasised discomfort in these discussions, they noted that it would be rare for people to raise issues with facilities management: "*I know that a lot of the time people won't say anything about the computers being broken.*" (S1G2), because "*I would not bother even telling if I didn't think it was going to change anything*" (S1G1).

Participants noted the self-selection biases inherent in feedback-gathering systems (**A2**), and an awareness that individuals with poorer (particularly thermal) comfort tend to complain the loudest: "*You'd need some sort of consensus […] rather than one person just being like 'yeah well it's too cold'…*" (S1G1). Furthermore, there was a perception that formal complaints have more weight than ongoing feedback in their power to resolve issues: "*… the issue's not a big enough issue until people complain about it.*" (S1G2) and "*… actual complaints would still be actual complaints… It depends on the effectiveness of the questions.*" (S1G2). It was important that participants should be able to set the agenda, disputing the effectiveness of the targeted feedback prompts from **A2**: "*you could have a general 'is there any feedback?' instead of printing a specific question because the person might […] want to give feedback on something else*" (S2G5). Feedback was therefore recognised as important, but issues of agency in raising it and in defining the agenda were seen as possible barriers to participation.

Facilities management are a nebulous group, hugely responsible but disconnected from building users. It is significant that the facilities management team are only ever referred to as "they" in data collected from both the walks and design exercises. "They" are a class of people in charge of the space, who have responsibility for changes made: *S3:* "*Oh look, they've finally installed comfy spaces.*" *S1:* "*Oh– I didn't even know they were planning on doing that*" (S1,S3G2). They also have responsibility for the allocation of resources and organisation of the space and for the maintenance of critical building systems: "*something happened with air conditioning […]* ***they*** *will try to fix it today*" (S1G1). Although this illustrates a distance between facilities management and occupants, and management were in some respects *othered* by participants, accounts from the free design task indicated that they are still seen as an important and necessary part of the organisation to facilitate participants' use of the building. Several groups designed solutions which situated facilities management as the authority with ultimate control over the space provided: "*[If] consistently the system found they can't satisfy students' requirements […] they will need to put more buildings, more space for this."* (S3G1) and "*… you could look at basically telling that to the University and then someone comes along to that room [and] reorganises it…*" (S1G1). Yet, a process of negotiation [16] was often also envisaged as part of this.

While participants recognised issues with the existing feedback mechanism for reporting issues, they still viewed it as an important channel for more serious problems. In designing for more inclusive buildings, other HBIs are also required, and these must find ways to go beyond information communication and crowdsourcing feedback to enabling occupants participate in shaping agendas.

HBI Must Account for how the Organisation Projects Itself, Within and Beyond the Building

The broader socio-political context of the University influenced student occupants' expectations of the building and the services that they perceived it should provide. Neoliberal perceptions of the university environment were revealed in how students saw the emphasis put on marketing by the institution: "*They sell it good, like, they market themselves good…*" (S1G3). Architectural features such as the glass-panelled windows in the computer labs exacerbated this by making students feel part of that marketing: "*you feel like you're like cattle, being stared at? So like waves of people come in and like stare at you, and it's really frustrating*" (S3G3). There was a sense that the building had been paid for by student tuition fees, and that problems with it therefore represented a lack of value-for-money: "*I just think, 15 million pounds or whatever it was for this building! And the aircon can't manage to last three weeks…*" (S2G1).

Tuition fees are a contextual factor through which the University projects its socio-political orientation. In the design exercise, participants rejected that it was their responsibility to solve these problems: "*It shouldn't really be the customer's responsibility to come up with the idea. Like they're offering us a service so we can tell them what we need and then they can try and do it and feed-back if they can't*" (S2G3). This illustrates a two-way influence of the socio-political context on HBI: building design decisions have knock-on effects, such as feelings of being 'marketed' being amplified and reproduced by the building fabric, and buildings and their processes are experienced and understood within and as part of this broader context. HBI cannot be separated from this context, but can potentially mitigate and challenge it. For example, HBI might enable spaces to offer different kinds of value to occupants, e.g. through facilitating different relationships with staff to that of a customer.

The Janus Face of Smart Building Data: Powerful Resource, or Resource for Power?

Smart buildings, as exemplified by our case study building, have the ability to collect, analyse, and act on data. Yet, while data can enable novel forms of interaction with the built environment, our student participants considered it Janus-faced, highlighting a range of associated concerns. Discussions about data generally occurred in relation to **A1** and **A2**, which encouraged participants to think more broadly about how this data might be used or annotated. Participants were aware that the building was logging large amounts of environmental data: "*we know that the [building] is supposed to be taking in a lot of data and that's kind of like its gimmick*" (S1G2). Among the range of issues extant in the data were concerns about invasions of privacy through tracking emerged in conversations around the collection and use of data as a result: "*Big Brother, innit, being tracked*" (S3G4). Language used also highlighted considerations of ownership of data: "*I really do like the idea of being able to interact with the building that's apparently taking all of our data as well"* (S1G2), leading us to question how data might be more equitably or transparently collected given the perception of ownership by building occupants generating it.

Yet, benefits of data collection were strongly present in the final free design task, where participants ideated on how data might be used, for example in enabling 24 hour access to the building: "*... and the University would be able to actually know who is in what, and this would help with the 24 hours control…*" (S1G3); in visualising busy areas to aid in selection of a workspace "*We've got a heat map down there which […] can show the busy areas*" (S1G2); and solving thermal comfort issues "*if you got the right consensus algorithm […] that would have a really good effect on working conditions…*" (S1G1). One group also asked whether staff and students working within the building might have the ability to create their own solutions if the data set were open: *S3:* "*You can access all of the readings, yeah*" S1: "*Like open data, just plug into the API […], you should be able to query all of it.*" (S1,3G1). Though there was a perhaps technologically-solutionist tendency within the designs produced, they often also offered potential interaction improvements, arising from issues identified through occupants' experience of the building and their participation in the walking activity: "*It would be useful if it told you the aircon was currently on […] because a lot of the time, like now, the aircon in here won't be on because that [smart] window's open*" (S1G1).

Students also debated the subversion of collected data: from more direct interference with existing systems "*People breathing on the sensors!"* (S3G4) to sabotage sensor equipment; to ways in which our diegetic artefacts might be exploited, for example relating to **A1**: "*it's pretty dodgy I think. […] It could maybe force you out of a place if it knew you had a general passiveness for not liking hot rooms– it could make the room hotter and things like that!*" (S1G1). The possibility of abuse of occupant-facing systems prompted alternate design suggestions: "*I'd say just have an API […] and then there's traceability if someone was completely being a dick or something…"* (S1G1) as students questioned whether they would trust other building users to act responsibly in settings with devolved management of the space. **A2** raised similar concerns that "*a lot of people would exploit it […] Do you think people would use it… properly?"* (S1G2) and suggestions for design changes "*We also had an idea of moving the whole system to be, like, an online system […] maybe that would help stop people from trying to exploit it…*" (S1G2). As students of an engineering discipline, our participants were keenly aware of the potential uses (and misuses) of data collected by the building.

Considering how HBI might account for ethical issues relating to the use of data, we highlight occupants' awareness of these issues and their ability to suggest mitigations. Through transparency and the involvement of occupants in conversations around how their data is used, smart building data can be used in ways which include rather than exclude building occupants. Future smart building HBI may leverage this dialogue as a powerful resource for inclusion.

DISCUSSION

We presented findings on how our smart building occupants conceptualised and understood the space they work in (**RQ1**), how this relates to perceptions of HBI and facilities management (**RQ2**), and how we might design agency and participation into students' everyday experiences of university smart buildings (**RQ3**). We raised the socio-organisational considerations for such designs in our findings. We now discuss how technology might grant facilities managers insights into the student experience; new digital ways for occupants to play a role in evaluating their building; and link these to HCI in generating design implications for future HBI and facilities management technologies. While we position our discussion for designers and practitioners in HCI and HBI, many will also be relevant to facilities managers and university management staff who may be best placed in implementing these in future buildings.

Communicating Agency to Building End-Users

Perception of control was important for providing feedback, with one participant saying that they would not even consider engaging if they "*didn't think it was going to change anything*" (S1G1) as reported on in our finding that *Mediation is Necessary in Shared Buildings*. Learned helplessness is an issue in scenarios with low levels of agency as highlighted by Hellwig [30], where people stop trying to exercise control if their activities have no effect on the situation. To begin to address this, smart building interactions should ideally include an immediate and visible response to communicate to occupants that their action was effective. With comfort systems this interaction is easily understood, for example, turning on a light or showing that the temperature has been recently adjusted on a display [44], but for furniture reconfigurations a preliminary date and time for when the work might be carried out could be given.

Facilities managers and automation technologies control occupants' space on their behalf. Agency to make changes and manage the space is locked down, for example by centrally controlled thermostats linked to BMS, or windows which do not open because the space is air-conditioned. Goulden and Spence [27] identify that responsibility for energy management has been centralised with the facilities manager. In the *buildings-as-a-service* model, changes must be requested through facilities management gatekeepers. While in the smart home context, users have more control over their surroundings (including over their automation technologies [41]) in an organisation this responsibility is deferred to management. There is potential to use data and technology to create flexible spaces, to give *more* control instead of less: *The Janus Face of Smart Building Data* hints at how this might be enacted through transparency and involvement of occupants in conversations. Thermal comfort has been extensively examined from this perspective [17], and it is well recognised that an increased *locus of control* is psychologically beneficial to feelings of comfort [29]. Comfort is not the only factor determining the fitness for purpose of a building, though, and it appears that designing for perception of control holistically could be approached as a starting point in improving occupant agency.

Ongoing Conversations may Lower the Bar for Feedback

Although techniques such as post-occupancy evaluation [10] exist as a method of directly engaging with building users, they are limited in that they are not used in an ongoing manner over the lifetime of the building. While students are lay-experts on the building [42], they have no formal training in facilities management: the perspectives of other building stakeholders will be valuable in order to bolster their knowledge and correct misconceptions [28]. Moreover, although participants were able to describe and discuss the pain-points of their experience (as in our finding on *Negotiating Shared Spaces*) these are difficult to get at for facilities managers through traditional feedback processes such as making a complaint [16]. This work suggests that there is potential in designing interactions which engage occupants in an ongoing conversation to ensure that the buildings which they inhabit are, and continue to be, fit-for-purpose. With its experience of user-centred and participatory design methods, and novel interaction techniques, HCI as a field is well positioned in its ability to respond to this challenge. Previous work has examined civic technologies [9], participation in planning [58], including voting technologies [56], sharing themes with the solutions designed by our participants. Such approaches might represent a starting point for beginning to understand how occupants might continuously collaborate with management in solving wider problems in the building.

Designing for Exploration and Spatial Appropriateness

Our findings surfaced forms of interaction by occupants with our studied building which were unexpected, for example, how the testing of smartcard access as a proxy for permission to use a space (see *How Opaque Space Rules lead to Unclear Affordances*) helped students to develop mental models of building permission. HBI might consider exploration when designing smart building interactions. Similarly, the *SpaceBot* diegetic artefact (**A1**) depicted a novel interface operated through the Twitter platform. While this received criticism for its susceptibility to abuse, we are reminded that criticism is a resource for design [55] which can be harnessed for creativity. While such interfaces allow for exploratory interaction, technologies of this kind differ in the extent to which the interaction is public or private. Twitter was understood as highly public and therefore not spatially appropriate. Local interfaces, or conversational agents such as Amazon's *Alexa* and Apple's *Siri,* have recently garnered attention from the CHI community [57] and may be better suited to this context as they allow spoken interaction. Furthermore, certain types of interactions (such as comfort complaints) may not be suited to a technology where they can be overheard, requiring more discreet forms of interaction, similar to the red/green LED display of the smartcard reader when granting or denying access to a space.

Booking was another form of interaction referred to by students, who viewed it as a way of guaranteeing access to appropriate workspace which met their requirements. Better access to information might alleviate the need for booking, which (as in our finding on *Securing Space*) may be at odds with the spontaneity inherent in the practice of finding a place to work. Participants suggested in the design activity that mobile apps may be a way to accomplish this, giving an easy way to access data on resource contention. Sensor-augmented smart buildings [42] offer a unique advantage in this regard as analytics can be performed to create occupancy data [36]. A solution as simple as visualising and feeding back expected occupancy levels would to allow planning for a future 24-hour period. Situated public displays offer another mechanism for accessing this information, and could enable more complex forms of interaction and negotiation [35], though these should be carefully designed and positioned [45] to allow for meaningful engagement. In short, both the technologies deployed within a space, and the

interactions and processes designed for them, must be spatially appropriate and account for the social context.

HBI's Role in Supporting (or Challenging) the Status Quo

While buildings management often seeks ways of managing that maintain the *status quo*, we consider that this might change in future. In the home, Mennicken et al's [41] provocation that "*smart homes will collaborate with their inhabitants instead of only being controlled by them*" is pertinent for non-domestic smart buildings too. Taylor et al [52] identified that the home should support the smartness (meaning intelligence) of its occupants, though in the work context 'smartness' will have different meanings, including e.g. fostering social interactions [13]. We need to shift the rhetoric of smartness away from automation back towards the human, so that smart buildings can be smart for occupants, too, not just building managers.

Still, management involves making trade-offs and coming to a consensus with differing opinions [16]. Perhaps a change in the culture of both managing and occupying buildings needs to occur in order for more radically reconfigurable buildings to become a reality. We must remember that *HBI Must Account for How the Organisation Projects Itself, Within and Beyond the Building*. Neoliberal management structures, processes, and cultures are a barrier, but the culture they create results in occupant disengagement: why take responsibility for the space when you're a customer? Although our participants rejected having a role in managing the building, they did care about having good space, and this could be better leveraged as stewardship if organisational practices and processes were put in place to enable them to contribute, and to de-centralise and distribute responsibility to more stakeholders. Tackling strongly held perceptions of social roles may be the first step in enabling more democratised forms of management. Directions for HCI/HBI to contribute to this agenda include designing technology to support decentralised responsibility for space management, democratising how decisions are made, and enabling bottom-up provision of resources. Furthermore, there is an open question for us as HBI designers and practitioners: *should HBI be designing to support service-oriented buildings management, or should it be disrupting the space*?

Participatory Auditing

Following our call that that buildings be continually evaluated and reconfigured over their lifetimes, we propose a technologically-mediated approach to engaging building users, which we tentatively term '*participatory auditing'* or PA. Specifying a methodology for PA is beyond the scope of this paper, but from the findings brought forward in this work we can suggest a manifesto for its central tenets, as follows:

Shift social roles: To reduce occupant reliance on a building-as-a-service model, social roles must be shifted to increase agency, and consequently responsibility. This relies on organisational culture change, as there must be support for this from across the stakeholder spectrum. Technology alone cannot achieve this. Grassroots approaches such as building occupants' unions might play a role here in proposing and achieving such change.

Promote collaboration: Collaboration between occupants and facilities managers is crucial for enabling more radical forms of facilities management; reducing the '*us vs them'* paradigm referred to in our findings. This depends on the aforementioned organisational change. It is likely that more progressive building designers and managers would be at the forefront of adopting new methods for this.

Enable reconfiguration: Occupants are domain experts in the problems they experience, but don't consider it their remit to perform more radical reconfiguration of space or just-in-time adjustments in-person. While the temporal aspect of changes is longer if management needs to be involved to action it, giving timescale estimates and timely up-front approvals or denials can alleviate this. Interaction should be handled by the building itself (for example, perhaps a conversational agent built into the room). No-one should have to send an email to request a change.

Disseminate information: Data should be leveraged as part of collaborative discussions with occupants as in [16] to allow informed conversations to take place, and to build expertise in understanding and interpreting data. Technology forms a part of this vision, by enabling novel ways of collecting information on problems, and providing new forums to facilitate their discussion. As HCI practitioners we can support forerunners in this space, and foster bottom-up solutions to challenge norms.

Limitations

There were limitations to this study, which we recognise. Primarily, we focused on one kind of non-domestic building, and with one type of occupant: students. We recruited across taught undergraduate and postgraduate courses, though some postgraduates worked in staff offices on doctoral training programmes. Future work must attend to other roles: academic staff and PhDs; administrative and support staff; and estates staff including cleaners. Although we conducted pilot interviews with other building stakeholders [44], we did not include those individuals in the workshop to avoid diluting the perspectives of our student occupants. Per [28], inclusive buildings management processes should be co-designed with this wider network of stakeholders.

CONCLUSION

We presented a study of student occupants of a smart building, resulting in new understandings of how HCI and HBI practitioners might design interactions that foster agency and participation in facilities management processes. Findings from a qualitative process including a building walk and speculative design workshop led to new understandings of students' situated experiences within the smart building, and socio-organisational concerns for the design of HBI. We suggest new directions for the HCI and HBI fields in this area, including an open challenge for future work to disrupt existing service-oriented structures in facilities management.

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