SpaceBot: Towards Participatory Evaluation of Smart Buildings

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Abstract
Smart buildings generate a wealth of data about the spaces they contain. Yet, in evaluating them against occupant needs, sensor data alone is insufficient. Our contribution lies in a re-framing of smart building spaces around the human factor, and a critical lens on the criteria used to evaluate buildings. We propose future work on participatory technologies to evaluate complex and heterogeneous built environments with the people who live and work in them, recognising that their expertise is invaluable in creating quality spaces and ensuring their ongoing and sustainable use.

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Introduction
Non-domestic buildings are a site of recurrent interest in HCI: vastly technical and complex spaces, a site of ongoing engagement with occupants and managers, policy and process, and an opportunity to address resource use. Office business premises in the UK consumed 23TWh of electricity[1] in 2017, making them a domain of ongoing concern for sustainability research. Evaluating space use in office buildings ensures that they are being used effectively, as design affects comfort, productivity [7], and energy use through occupants' practices [22]. In addressing this,

[1] Source: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes

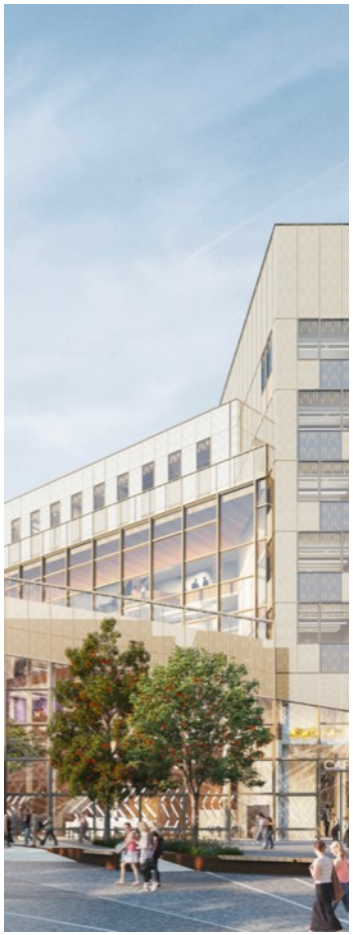

Figure 1: Pre-occupancy artist's impression of the Urban Sciences Building (USB) at Newcastle University. Image (cropped) © Hawkins\Brown Architects

we bring together multiple threads of thought in HCI across Human-Building Interaction (HBI), Sustainable HCI (SHCI), and place-making. As Alavi et al. [1] state in their CHI2016 HBI workshop, the ways in which we interact with buildings are changing as a result of their ongoing technological enablement, and that buildings "*should be designed and nurtured in a dialogue with their users at the individual as well as social levels."* Our work contributes to this agenda by seeking to understand the roles of data and the individual in the design, management and evaluation of smart buildings.

Modern non-domestic buildings often include highly granular data collection capability via their Building Management Systems [3]. However, building managers have difficulty engaging occupants in processes of ongoing feedback [7,20], as communication occurs only when discomfort results in a complaint. This project aims to explore the complexities of space within a "smart" office building, examining how HCI might support participation in its ongoing re-configuration and management. Leveraging understandings of space and place developed in prior literature [8,10,18,19], our orientation foregrounds occupants and their practices. Through dialogue and appropriation of the space in different ways, spaces go through an ongoing process of recreation by occupants. Therefore, approaches to evaluation are required that go beyond e.g., optimising resource use or meeting design specifications. The meaning of the quality and sustainability of a space are dynamic and cannot be disconnected from occupants' experiences and perceptions of it.

The newly constructed Urban Sciences Building (USB) at Newcastle University (Figure 1) is a "*living lab*" for sustainability research (Figure 2), and is the site of investigation for this work. Its occupants are diverse: office workers (academic and admin staff) and students. We have found in our initial work that occupants are framed as "users" of the space, as opposed to co-creators. We argue that this disengages them from re-configurations and re-negotiations of it, and could encourage unsustainable adaptive actions (e.g. to thermal climate [7]). Our investigation has focused on the provision of amenities for students: engaging with senior staff to understand existing processes, what can be changed, and what cannot. We develop design sensitivities for how this data might be used as part of sensor-driven services positioned to building occupants, and to facilities managers for evaluation of the building's sustainable architectural design and the auditing of future space usage policy.

Related Work

In the literature, built environment data has been leveraged to improve management of the buildings in a number of ways. The first is in control applications where inefficiencies are optimised to enable more sustainable use of resources. For example, machine learning may be performed on data sets including *occupancy* [17] to achieve energy savings in heating or lighting usage. Modern building management systems (BMS) are well developed for this purpose. However, these are highly complex systems that can be difficult to adapt [3]. In older buildings without modern BMS, lightweight retrofittable sensor systems [20] can provide a fall-back method for data gathering. Such data can be used for formalised audits of buildings [20] and providing recommendations and advice [11].

A second approach attempts to influence what people do in the built environment through *eco-feedback*. The

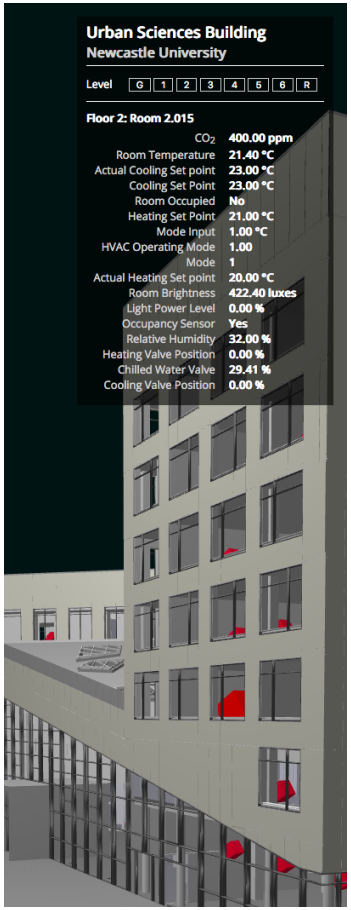

Figure 2: A screenshot from a spatial visualisation created using data [15] from the Urban Observatory, Newcastle University.
For more information, please see: http://urbanobservatory.ac.uk/

site for this is often domestic, with participants being encouraged to take energy-saving actions through e.g. eco-feedback displays [12] or nudging awareness-raising of environmental impact [16]. Interventions in this domain are criticised for not accounting for novelty effects [4], and for framing sustainability as an issue of personal choice for rational actors [23]. This approach is problematic as such studies assume that human actors are able to make (and sustain) rational decisions about minimising energy use.

Finally, recent work has examined re-framings of resource use in the built environment. Adaptive thermal comfort [21] posits that space heating can be more sustainable by regulating environments less uniformly and encouraging occupant interaction. Clear et al. [6] replaced temperature set-points with an approach more closely aligned with occupant experience, using sensor data to control heating in ways that encourage active "achievement" of comfort by occupants. In the office context, interactive systems and data open up ways for occupants to participate in comfort management processes, which the heating and cooling and Facilities Management industries have largely designed them out of [5,7]. Automation (particularly in smart buildings) decreases occupant agency, but approaches that bring different stakeholders into the loop can address this.

These approaches take perspectives on improving smart buildings and spaces that either focus on building infrastructures and resources (e.g. energy), or services (e.g. thermal comfort). Definitions of the quality and sustainability of spaces are often much broader than this, not clear-cut, and dynamic. In the following section we draw on theories of space and place to try to grapple with these properties and to reconceptualise what evaluation and management might mean from this perspective, and how it could be achieved.

Space and Place

HCI researchers have drawn on understandings of space and place developed by geographers and philosophers over the past 30 years [8]. McCarthy and Wright [19], for instance, conceptualise places as dialogue, being necessarily a site of flux that should not be viewed as static—and this may be especially true for technologically enabled places. Massey [18] reveals a complex interplay of power, politics and people in her conceptualisation of place. She presents place as highly heterogeneous, perceived differently through differing gender, social position, race, inequality and so on: having different meanings and nuances which become apparent depending on the viewpoint of the individual. Understanding places as being continuously created by those who inhabit them, Massey notes that "*places are processes, too*". Of considerable influence within HCI itself is Harrison & Dourish's [13] development of these notions in relation to CSCW technologies. Yet, as both space and place are created as "*products of social practice, albeit different systems of practice,*" Dourish [10] argues against the dualism inherent in separating the two concepts. A more formalised approach, *space syntax* [14], describes physical spaces in terms of both their topology and the sociological constraints which dictate their design and use.

Drawing on these conceptualisations, taking a space-based approach to the evaluation and management of sustainable buildings involves accounting for (i) multiple perspectives and viewpoints [18], (ii) the dialogue or negotiation of all stakeholders involved in its construction [19], which might take place through

Figure 3: Existing engagement of the estates management team with students and staff on-campus via Twitter

Preliminary staff interviews were undertaken with:
a) a senior professor in the department;
b) a departmental manager;
c) a building manager and;
d) a senior manager in the Estates Support Service.
All were involved from an early stage in the design of the building, and were anticipated to have particular expectations of its modes of use (as a building and as a living lab) as a result.

the performance of practices [13], and (iii) the ongoing nature of this of this process [18,19]. We see this as highlighting a gap in the *everyday* elicitation of accounts from occupants of what spaces are for and how they are experienced, and support for the negotiation of this in ways that are inclusive for all stakeholders. Clear et al. [7] investigated how sensor data can serve as a platform for achieving some of these properties in relation to workplace thermal comfort. However, in this work in the context of smart sustainable buildings and the continuous creation of space [18], we take a step back and ask how interactive systems might also enable building occupants to participate in defining the very terms under which spaces should be evaluated.

Methodology

Smart buildings create huge amounts of data, but there is a challenge in how this data can be made accessible and usable by building occupants [7], and a question in the ways this data is used to determine use of the building's spaces. The building we focus on is a "living lab", a concept in this instance predicated on the idea that collecting more data, and giving researchers access to that data, will allow policy makers and building managers to make better decisions through collaboration. The importance of work which focuses on how to use buildings more sustainably cannot be understated, but what do we *mean* in managing *this* space more sustainably? One metric for measuring and quantifying this might be utilisation: having built the spaces, ensuring that they are suitable for use according to the perceived requirements of inhabitants.

Open-plan spaces for student study are available for use during gaps in the teaching schedule. These spaces are interesting to look at as a case-study as they are highly reconfigurable, a possible site of intervention. Preliminary semi-structured interviews were undertaken with four key staff stakeholders, with the thematic analysis of the interview corpus currently ongoing. Our motivation was to find out how staff conceptualise building space and its evaluation, and generate understandings of which aspects of building use should be addressed by our study. Ongoing further work will include focus groups with student occupants, to understand their perspectives on use of the building.

The initial open-coding of our corpus produced 268 codes, however, prior to synthesizing themes our intention is to re-analyse this data using the lens of previous literature on space and place: for example, coding for *social practices* to acknowledge that space and place are products of these [10]. Our findings from the thematic analysis of these codes sensitise the design for our technology probe by bringing in understandings of how space and place are constructed by staff. Through this, we investigate how the building's users themselves might be more meaningfully engaged in on-going feedback processes, and how sensor-driven services might support re-negotiations of their space.

Future Work

Our initial interviews have revealed that departmental and facilities managerial staff want to evaluate use of the building's study spaces. Evaluating and improving these spaces is important for student experience, but the metrics by which we evaluate effectiveness are unclear and dynamic. Post-occupancy surveys are an existing method to investigate this, however, these are short-term, top-down, static and pre-defined. These methods limit the scope of what occupants can feed

Questions for our *SpaceBot* probe

There are a number of open questions we consider important to investigate through our probe:

- How do we include occupant perspectives on what the building should be evaluated for?
- How do we include flexibility for criteria to change and evolve, to closer relate to experience?
- How do you do this in naturalistic (not burdensome or onerous) ways?
- Is Living Lab data engaging as part of this?
- Can occupants get value from this data, or can they add value to it with qualitative feedback?

Twitter presents a media-rich, engaging environment through which to investigate these questions. Occupant feedback can also be collated and made accessible to facilities and departmental managers.

back on, and are structured according to ideas of quality space use by the construction industry. As such, we propose combining quantitative smart-building data with qualitative occupant data to investigate this. Our initial work indicates that timetabling, building layout and location affect how students use these spaces. In engaging them, however, we acquire richer data on the motivations for using particular spaces over others.

Twitter Probe: SpaceBot

Our technology probe, *SpaceBot,* investigates how we support user participation in the management of smart buildings, i.e. how to engage people in a process of providing everyday feedback on space use. Twitter has received wide attention within HCI research: a microblogging platform and source of user-generated news content, and a mouthpiece and communication channel for organisations. These affordances have made the platform an engaging feedback mechanism for organisations in the management of their built estate (e.g. Figure 3). Twitter 'bots' (autonomously tweeting robotic agents) can be easily developed and deployed, reaching a wide audience. Tweeting smart buildings therefore represent an opportunity to investigate new modes of space use: combining agent-based interaction with the existing use of the platform by organisations for communication and feedback is a novel approach to the management of building spaces.

Our technology probe is characterized as a personified smart agent, to capture occupant dialogue *with* and *about* a smart-building. The "building" (our *SpaceBot*) is concerned with how people are experiencing it, and in developing better understandings of what the state of the building (from the sensors) means in terms of occupant experience. It may 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. Through our probe deployment, we hope to gain insights about evaluating smart-buildings, and the role of occupants and in-place sensor data in realising this.

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