Studying Space Use: Bringing HCI Tools to Architectural Projects

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ABSTRACT
Understanding how people use different spaces in a building can inform design interventions aimed at improving the utility of that building, but can also inform the design of future buildings. We studied space use in an office building following a method we have designed to reveal the occupancy rate and navigational patterns. Our method involves two key components: *1*) a pervasive sensing system that is scalable for large buildings, and high number of occupants, and *2*) participatory data analysis engaging stakeholders including interior architects and building performance engineers, to refine the questions and define the needs for further analyses through multiple iterations.

In this paper, we describe our method in detail, and exemplify how HCI methods and approaches can contribute to professional building design projects.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Human-Building Interaction; HCI in Architecture; Post-Occupancy Evaluation; Participatory Data Analysis.

INTRODUCTION
The contribution of buildings to global energy consumption is steadily increasing, exceeding 20% in developed countries [28]. This has raised serious ecological concerns about the amount of resources spent to provide comfortable indoor environments. On the other hand, considering the fact that we spend 90% of our time inside built environments [14], the quality of indoor experience cannot be compromised. Therefore, attempts at designing sustainable buildings need to be grounded in the knowledge of how they are utilized by their occupants, and the user experience that they offer.

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Moreover, the user experience in architectural contexts has started to embody new aspects, subjected to an increased incorporation of interactive technologies into the built environments. This further pronounces the need for expanding the involvement of HCI research in the design of future buildings [21]. This is the main motivation behind the emerging notion of Human-Building Interaction (HBI) [1, 2], which calls for further examination of such possibilities for the two disciplines of architecture and HCI to work together. Owing to the richness of knowledge and methodologies belonging to these contributing domains, HBI can inherit, assimilate, and thus develop a cumulative understanding of evolving human living and working behavior, as well as design for these demands.

The symbolism of HBI manifests in the suggestion for architects and HCI researchers to share knowledge and learn from each other. This idea of sharing and learning is increasingly recognized not only in recent theoretical discourses [8, 39], but also on a more concrete level by combining the methodologies and re-appropriating them for the problems at hand. For example, Sempere [32] combined prototyping with ethnography of space. He used a theater scene as a place where rapid prototyping of alternative spatial and social arrangement is possible. In the context of performing art, Sempere studied how "computational ideas" integrated into the play alter our understanding of the place. De Maat [11] used a participatory method to gain insight into the mental model of the building. He created a setting where the occupants of the building could engage in sketching on paper a shared image of the space.

Despite several instances where the disciplines of interaction design and architecture have drawn on each others' knowledge, concrete collaborative projects among the two communities have rarely been pursued. This was one of the concluding points of the CHI'16 workshop on the "Future of Human-Building Interaction" [2], as stated by the organizers. In this article, we report on one such experience of amalgamation that manifested itself in the form of a longitudinal and iterative understanding of space usage in an office building. This is accomplished through a collaborative project with the other stakeholder in six phases, which we elaborate in the following sections. The stakeholders and collaborators comprised of a team of interior architects, building performance engineers, and HCI researchers. This article reflects on this collaborative project from an HCI point-of-view, and discusses the lessons learned, especially the ones that concern with a key methodological question in HBI: "How can HCI research methods be made more compatible with the architectural design process?"

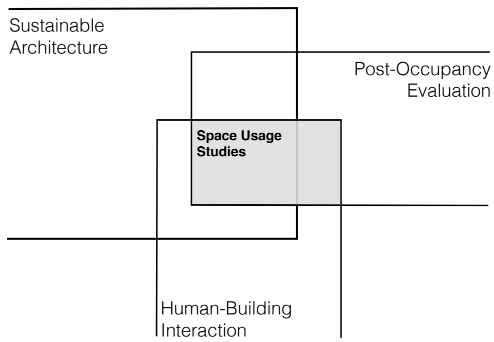

Figure 1. The study of space occupancy in architectural context is part of the Post-Occupancy Evaluation and Human-Building Interaction domains, with applications for sustainability.

RELATED WORK

Our contribution falls at the intersection of HBI and Post-Occupancy Evaluation, with applications for Sustainable Architecture, as illustrated in Figure 1. This section describes in more detail the position of our work among related research domains.

Post-Occupancy Evaluation

Post-Occupancy Evaluation (POE) consists of a set of methods to study the performance and user experience of buildings once they are occupied [30]. POE, in the short-term, can identify the problems of the building and help improve its current state through interventions; in the medium-term, it can inform design of the next building cycle; and in the long-term, it can create a database of lessons to guide the design of future buildings.

Given the high complexity of building systems, POE methods include a wide range of multi-perspective qualitative and quantitative tests. For example, the physical products of a building, namely the thermal, visual, acoustic, and respiratory comfort should be assessed alongside the energy efficiency of ventilation and illumination systems (for example case studies see [38, 29, 25]). Also, the social products of the space and the psychological comfort should be evaluated alongside the space utilization [15, 36]. Additionally, recent studies have shown a significant degree of influence of psychological factors on the perception of physical comfort [27, 34]. POE researchers have examined various methods and tools. Basic parameters such as temperature, air movement, light intensity, and pollutants are sampled and measured following the traditional building physics approaches; walk-through observations are used to identify building flaws; and surveys and questionnaires to unveil the intricate interactions between a building and its users.

Our work contributes to the sub-class of POE research that studies the use of space. In that sense, it is most similar to the work of Stevenson [35] who used the occupants' self-declaration to investigate the correlations between spatial qualities of the building and users' satisfaction in the context of a social housing project in Scotland, and the work of Gonzalez et. al. [16] who employed ethnographic observations to study the use of corridor spaces in a hospital. The pervasive sensing method that we examined does not have the disadvantages of self-declarative survey research [20] and, as opposed to field observation, it allows for scalability both in terms of duration of study and number of participants.

There is an increasing recognition that POE is an essential phase in the construction process of sustainable buildings [24], simply because optimizing resources entails a thorough understanding of how the occupants use and experience the building. In the following section we will review the role that HCI plays in sustainable design, and describe the position of our contribution in that field.

HCI in Sustainable Professional Design

Following Blevis' definitional manifesto on sustainable interaction design [5], there has been a remarkable growth in sustainable HCI research in various orientations and genres. Mankoff's well-adopted classification suggests two series of issues [23]: *1*) sustainability *in* the material design of the products, for example, by better recycling of the computational devices (e.g. [19]), and *2*) how to promote sustainable lifestyles and decision-making *through* technologies by informing individuals about the environmental impact of their decisions and encouraging alternative pro-environmental behavior (e.g. [4, 17, 7]), or by sensing the state of our environmental resources and how they are utilized (e.g. [18]). This last aspect is part of the sensing literature, to which HCI and Ubicomp have contributed with the two emerging notions of participatory and pervasive sensing. In participatory sensing the emphasis is on the individuals' participation in the sensing process [6]. This has become possible because of the ubiquity of daily mobile devices that are equipped with multiple sensors, which has made the collection of richer, more varied, and real-time data possible. For example, Mun et. al. [26] introduced a sensing system called PIER that engaged people in collecting data about their urban trips and computes the environmental impact and exposure. In the Biketastic project [31] the bike commuters' mobile phones sent their location, accelerometer data as indicators for road roughness, and the ambient noise level to a server.

Pervasive sensing is a technique that draws upon the concept of calm computing to observe individuals and their interactions. Such systems often use ambient and/or wearable devices to collect data. Atallah et. al. [3], for example, combined ambient blob sensors and wrist-bands that emit Bluetooth signals to model patients' activities inside a hospital and discern abnormal behaviors.

Our contribution, similar to Atallah's, is a system of pervasive sensing and analysis of behavior profiles, although it aims at a different goal: to inform architects about the space usage as one of the axiomatic parameters of post-occupancy - an inevitable step towards sustainable building design. DiSalvo et. al. in their 2010 literature review of "Sustainable HCI" [13], pointed out the "severely problematic disconnect" between HCI in sustainability and professional design communities (e.g. industrial design, architecture, urban design). Our work is also an attempt towards bridging this gap.

BACKGROUND & COLLABORATORS

Within the framework of `Smart Living Lab`[1], a confluence of researchers from the domains of HCI, architecture, mobility, and building performance confronted themselves with research questions that concern the future of built environments. These are addressed through the development of a prototype: a building, which can accommodate up to 100 office workers, is used both as the site for conducting user studies and as the platform for developing design ideas.

The sub-project that we describe here focuses specifically upon the affordances of spaces in this prototyped building and their interaction with the varied situated activities and the profile of the actors who perform them.

The contributors in this sub-project comprise of the following groups:

- Interior architects from `atelier oï`[2] henceforth referred to as Studio *A*
- Building performance researchers from `Building 2050`[3] henceforth referred to as Lab *B*
- HCI researchers (authors of this paper)

In the following sections we will describe the steps that we collaboratively took, starting with the brainstormings that consolidated the initial questions, followed by the details of the ethnographic study, the iterations of data analysis, the metamorphosis of our initial questions, the results, and their design implications.

PHASE I. PROJECT CONCEPTUALIZATION

At the scale of an entire building, space use optimization, also referred to as "intensification of space", can have positive environmental impacts, attributed to the reduced need for building materials and energy for heating and ventilation. This is a recognized step towards sustainable building design, and being one of the main research directions in Lab B, it was proposed to be further investigated in our project.

Intensification of space, as illustrated by van den Dobbelsteen and de Wild [37], can be achieved in three possible ways: *a*) adding more building layers; *b*) intensification of *surface* (e.g. increasing the occupancy rate); and/or *c*) multiple use of surface (e.g. designing spaces that allow for multiple activities). Constraints associated with building additional layers ruled out the first option, and limited our choice to the latter two.

The challenge with intensification of surface is that it can have negative impacts on the perception and experience of space, and consequently on the psychological well-being of occupants. On the other hand, multiple use of surface, for example by desk-sharing, might induce a perception of detachment with the space and disrupt the desired work dynamics [10]. These led the group to the following design challenge: How can we intensify the use of space without compromising the users' comfort or productivity?

[1] smartlivinglab.ch
[2] atelier oï: https://www.atelier-oi.ch/
[3] Building 2050: building2050.epfl.ch

Studio A, based on their prior design experience, suggested that reconfiguring the interior architecture, for example by introducing new office furniture, can increase attractiveness of shared spaces and mitigate many of the practical problems such as acoustic and visual distractions. Such reconfiguration, however, necessitates a thorough understanding of how the inhabitants use the different work-spaces, at the individual as well as social levels. Therefore, we (the HCI research team) suggested conducting an ethnographic study that could provide empirically backed insights into the design challenge.

PHASE II. COLLECTING DATA

Technical Setup

To address the discussed concerns, we needed to record the occupancy information comprising of a participant's presence (or absence) in different rooms, at short time intervals. Unlike indoor localization [22] that enables provisioning for accurate coordinates of an individual within a space, we were only interested in zoning (i.e. documenting the presence of an individual within a particular room at any time). We monitored 12 rooms (seven offices, three meeting rooms, one cafeteria, and one atrium space at the center of these rooms) distributed over three floors within the `Smart Living Lab` building (see Figure 3). These 12 zones represent most of the occupied spaces in one section of the building.

In each of these 12 zones we deployed a Bluetooth data-logger as shown in Figure 2, which works on a Raspberry Pi 2 Model B[4] with 8GB of memory to store data. These data-loggers were programmed for industrial sensing applications, and acquired from Starnberger Innovation & Technologie[5].

Each participant wore a bracelet (as shown in Figure 2) that embodied a Bluetooth Low Energy Beacon (EMBC01 from EM Microelectronic, Switzerland[6]). Each Beacon was configured to broadcast a packet containing its Universally Unique Identifier (UUID) every second. These packets were received by the data-logger in close proximity to the sender (corresponding to the room that the user occupied). Along with the Beacon's identifier and the timestamp, the data-logger

[4] Raspberry Homepage: https://www.raspberrypi.org
[5] Starnberger Innovation & Technologie: http://www.tokencube.com
[6] EM Microelectronic: http://www.emmicroelectronic.com/

Figure 2. One data-logger per room, and one bracelet per person was used to collect the occupants' location data.

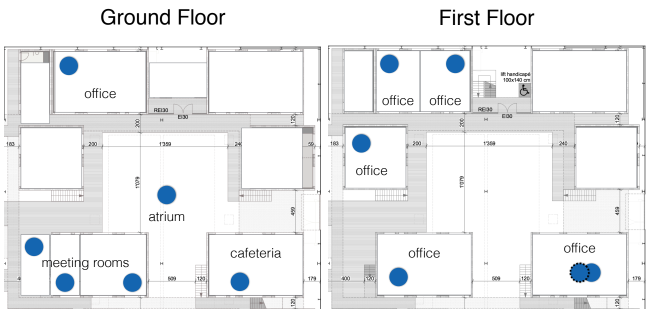

Figure 3. The plan of the ground and first floor where we studied space usage for two weeks. Each circle illustrates the position of a data-logger (the dotted circle corresponds to the data-logger at the second floor).

recorded the RSSI (Received Signal Strength Indicator) value indicating the strength of the received packet, which enabled us to filter out noise from the data as we will illustrate in the following section.

Furthermore, during their time in the office building, the participants were asked to wear their assigned bracelet, and after work to take the bracelets with them. In addition, a sign was placed at the entrance of the building to remind them to put on their bracelets upon arrival. During the course of our study we did not encounter any situations where participants had forgotten their bracelet at home.

Our decision to choose this technology over the other alternatives was principally driven by three factors: *a*) pervasiveness; *b*) privacy; and *c*) accessibility. In this regard, we chose Bluetooth Low Energy Beacons contained within a bracelet because of their small size and light weight, which renders them unobtrusive and indistinguishable from a conventional fitness-tracker or watch (see Figure 2). Unlike with camera-based tracking systems, users don't perceive a direct invasion of their privacy. Furthermore, relatively lower costs, and longer shelf-life (with batteries that function for months) make them more accessible compared to other methods such as WiFi-based localization.

Participants

Twenty participants (7 females, 13 males) affiliated to two different academic institutions (Swiss Federal Institute of Technology in Lausanne and School of Engineering and Architecture of Fribourg), participated in our study for a period of 12 working days. The participants held varied professional responsibilities and belonged to seven different professional profiles (two professors, three researchers, five architects, two civil engineers, two technicians, three project managers, and three members of administrative staff).

Procedure

The steps that we followed during our ethnographic study are illustrated in the list below:

1. One week prior to the start of the study, the participants were briefed about the goal of our study and what was expected from them. In addition, we dedicated a significant part of this session to elaborate on the data-protection and privacy concerns associated with our study. Particularly, we communicated in a transparent manner, the various steps undertaken by us to ensure data-protection by *a*) anonymizing the sensor data as well as aliasing the questionnaire and interview data; *b*) encrypting the data before storing; *c*) assuring not to share the data with anyone (including their employers); and *d*) providing them with a choice to withdraw from the study, or request deletion of their data. These details along with other relevant information was also provided to the participants through an "Informed Consent Document", which was signed by both the experimenter and the participant.

2. The participants received their bracelets on the first day of the study upon arrival in their offices. In addition, we also reiterated the instructions concerning the use of bracelets.

3. The study concluded after a 12-day period, and subsequently the participants were asked to fill out a post-study questionnaire.

4. A subset of participants were semi-formally interviewed about their daily routines, preferences and social interactions in the building. We chose the interviewees based on their space occupancy profile, which was the outcome of the first round of data analysis (discussed in the following sections).

Collected Data

The data-logger in each room stored the presence of participants in that room every second. As the packets transmitted from a Beacon were occasionally received by the data logger in the neighboring rooms (especially for the smaller offices), we filtered out the false positives by comparing the signal strengths. Then the logs from the different data loggers were merged into a single database, and additional features such as time spent in different spaces, and transitions from one room to another were computed. A detailed description of these features is provided in the next section.

The post-study questionnaire was inspired by the discussions that we had during the conceptualization phase with Lab B and Studio A, and was designed to collect basic information about the participants' work practices and professional responsibilities. We asked the participants about their work-from-home preferences, if they have more than one office (in different locations), and the number of colleagues with whom they shared their office space. The participants also elaborated on the varied activities that they generally participated in during a work day (formal and informal meetings, individual work, coffee breaks, etc.), as well as the approximate (perceived) time they spent on these activities. The semi-formal interviews were conducted after the data analysis but before translating the results into design implications. We asked the interviewees about how they used the building in its current state, their willingness to share workspaces, and how they would make changes in the configuration and function of space.

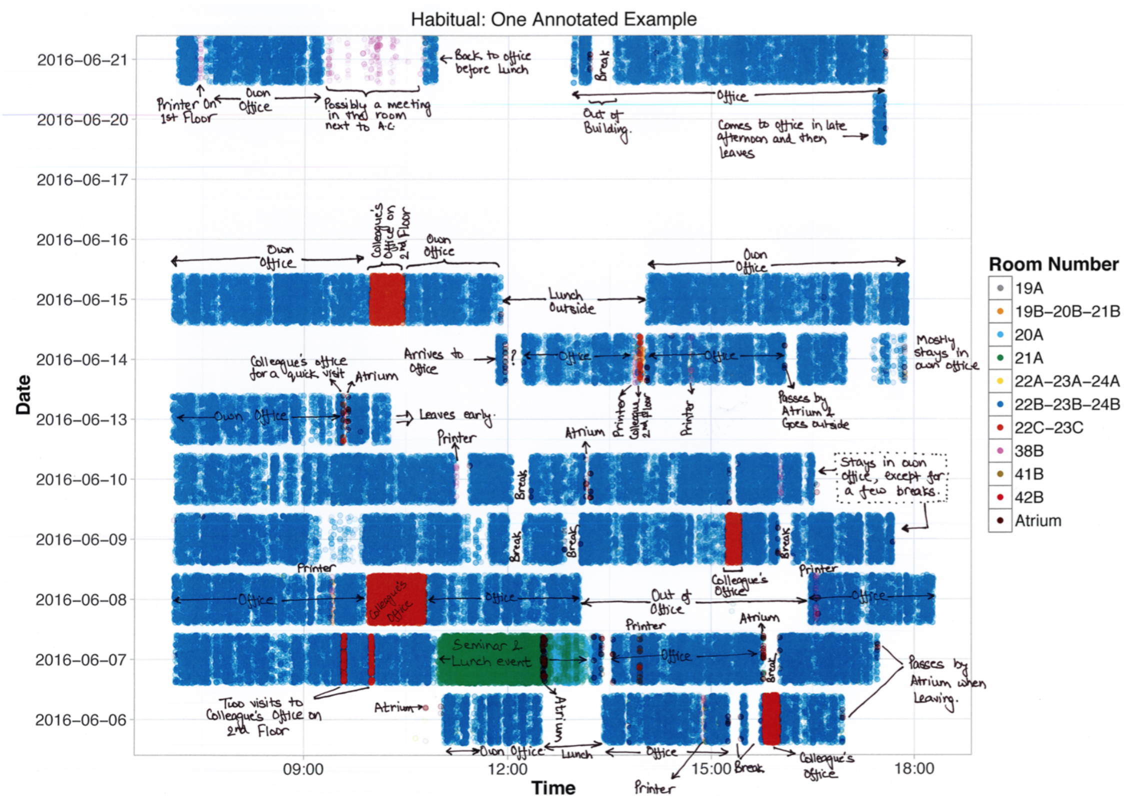

Figure 4. Visualizing the space occupancy of an individual as a Jitter plot. Each data-point denotes a Bluetooth packet from her bracelet. The color of the circle indicates the closest data-logger that received the signal, and hence the occupied room. The X-axis corresponds to the time of a day, and the Y-axis represents the different days of our study.
All the visualizations of this kind (for each participant) were printed on A3 papers and annotated with extra information about the participant's individual and social activities, which we extracted using the questionnaire data and our background knowledge about the context.
This occupant is an example of a Habitual.

PHASE III. VISUAL EXPLORATION OF THE DATA

We started the first round of data analysis with the visualization of the signals received from each Beacon in different data-loggers. That immediately uncovered the presence of the participants in different rooms. For example, Figure 4 shows the Jitter Plot of the signals received from a person's bracelet in different color-coded rooms, on different days. The blue room is her office, the red is her supervisor's office, and the green is one of the meeting rooms. Each received packet is represented with one tiny circle; the higher the signal strength the more opaque the fill-color. Then, we tried to annotate the visualizations with the pieces of information that we could visually extract about each person's individual activities (e.g. office work, coffee break) and their social encounters (e.g formal meetings, informal chat at common spaces, informal continuation of a formal meeting in the cafeteria). Finally, in order to validate this quantitative understanding inferred from the bracelet data, we organized a post-experiment session, and presented to the participants (privately) their visualized data. Through the discussions, it became clear that the collected data does correspond to the participants' perception of how they used different spaces.

Upon annotation and visual analysis, we observed a division of the population into two broad classes:

- *Habitual*s, were the ones who generally had certain daily routines (for example, arrival and departure times, time spent in their own office, coffee and lunch breaks); their occupancy within the office building was predictable at a specific time of the day. Figure 4 demonstrates a typical example of a Habitual person.

- *Mutable*s, on the other hand, were flexible in terms of their work schedule, and did not exhibit a strong association with their workplace.

We communicated the preliminary results to the stakeholders, and then arranged the second session of visual data analysis, this time with Studio A and Lab B (see Figure 5). In this session, we began with a brief explanation about how to read the visualizations (which we printed on A3-sized sheets and annotated beforehand). Subsequently the collaborators continued with individual exploration of data, and open opportunistic discussions. Among other points, the notion of "similarity", was repeatedly raised and discussed from different perspectives.

The similarities in space usage behavior are not necessarily corresponding to the commonality in the professional responsibilities held by the colleagues, which is static and invariant over time. On the contrary, they are often driven by social motivations and are opportunistic. For example, an individ-

Figure 5. The HCI research team invited the other stakeholders to collaboratively explore the annotated visualizations of participants' space usage behavior. The picture was later recreated.

ual might invite her colleague to go for a coffee break, while using the opportunity to have an informal discussion. In this example, the trajectories of these two co-workers are intertwined. Extending this example to a normal work day, we came across instances where colleagues were highly similar in their mobility. This similarity is related to the notion of Social Navigation [12], where one individual might follow the trace of a colleague in a synchronous and dynamic manner, and might also indicate collaborative activities within certain spaces.

Visual analysis of such similarities between co-workers is tedious and requires comparing the annotated occupancy data of individuals with that of their colleagues, and thus is not scalable for larger populations. Therefore, we applied Principal Component Analysis (PCA) on the occupancy data to *a*) investigate the relationship amongst different variables corresponding to the space usage behavior, *b*) mathematically identify the significant features, and *c*) accumulate them into factors which can foster a meaningful interpretation of behavior patterns. At such an exploratory stage of data analysis, our choice of PCA over other clustering approaches was primarily driven by our need to identify the (selected few) pertinent variables (or their combination) that can describe the data better, rather than studying the division in data across established boundaries.

PHASE IV. SPACE USE BEHAVIOR PROFILING

Prior to performing PCA, we computed the relevant process variables from the occupancy data, which comprised the input set for the PCA. These variables accounted for the daily behavior and mobility of the participants within the office building. Broadly, the variables could be classified into two categories corresponding to the time spent in varied spaces, and the frequency of certain actions that are suggestive of the office dynamics.

Process Variables

In the following list, we summarize the different variables that were used in the PCA:

- *Temporal Variables* represent the time spent in different functional spaces by each participant during a day. We computed the time that the participants spent *(1)* in their own office (corresponding to focused individual work), *(2)* colleague's office, *(3)* meeting rooms (indicating collaborative work), *(4)* cafeteria (representing free time or informal meetings), and *(5)* out-of-office space (Atrium, where participants performed varied activities such as phone calls, trip to printer rooms, etc.). In addition, we computed *(6)* the standard deviation of variables 1 – 5, which corresponds to the disparity in the length of time that an individual spent in different spaces during a day.
- *Frequency Variables*, including *(7)* transitions, which refer to the episodes when an individual moves from one room to another. A higher number of transitions might signify the degree of mobility of an individual. *(8)* The number of unique rooms that an individual visited during a day. Interruptions can be defined as the visits to the others' office spaces, while excluding the spaces of public nature such as meeting rooms and cafeteria. We computed *(9)* the number of times individuals were interrupted by the others, as well as *(10)* the interruptions they caused. In addition, we counted *(11)* the number of unique rooms that were interrupted by an individual during a day.

It is worth noting that, while some of these process variables are interrelated, each corresponds to one distinctive aspect of space usage behavior. Furthermore, these process variables were normalized for a normal work day before the PCA.

Principal Components and their Interpretation

We performed PCA on the process variables along with the participants' identifier as a qualitative supplementary variable. The first five principal components (or factors) collectively explained 77.45% of the variance in the data. However, only the first three factors (accounting for 60.9% of variance) demonstrated the emergence of meaningful categories of work behavior as illustrated by the correlation coefficients with the process variables in Table 1. Therefore, we considered these three principal components for the rest of our analysis.

Messengers

The *first* factor exhibited strong correlations with the variables corresponding to an employee's need for communication and coordination with others, by means of an elevated extent of mobility within the building. This is highlighted by the variables such as the number of different spaces visited during a day as well as the time spent while traversing the atrium. Moreover, the short-term recurrent activity of interruptions indicate the process of coordinating varied tasks with other colleagues. Further examination demonstrated that individuals with higher mean scores along this principal component were similar in their professional profiles and belonged to the administrative staff (secretaries and technicians). In addition, the correlation with the time spent in one's own office further justifies this finding because the administrative staff belonged to the category of Habituals and their work responsibilities also entailed individual work in their offices. Therefore, based on these observed correlations and interactions with the work behavior of a specific profile of participants, we hereby refer to this aggregation of variables (first principal component) as *Messengers*.

	Principal Components		
Variable	*First*	*Second*	*Third*
1. Time in Office	0.535	0.778	-
2. Time in Colleague's Office	0.355	-0.309	-0.432
3. Time in Meeting Rooms	0.275	-0.305	0.558
4. Time in Cafeteria	0.278	0.483	-0.263
5. Time in Open Space	0.566	-	-0.161
6. SD of Time Spent	0.569	0.738	-
7. Transition Frequency	0.297	-	0.737
8. Unique Rooms Visited	0.743	-0.174	0.398
9. Freq. of getting Interrupted	0.596	-	-
10. Freq. of Interrupting Others	0.747	-0.406	-0.252
11. Num. of Rooms Interrupted	0.744	-0.430	-0.164

Table 1. The statistically significant correlation values between the process variables and the first three principal components. The values which were not significant were removed from this table. Please note that the first three factors collectively explain 60.9% of variance in the data.

Workers

The time spent in one's own office (focused individual work), and in the cafeteria (corresponding to free time or informal meetings) was found to be correlated to the *second* principal component. Also a strong correlation with the standard deviation (variable 6 in Table 1) was observed, which indicates a high disparity in the amount of time spent in varied functional spaces during a work day. Further, the frequency of interrupting others and the number of spaces interrupted were found to be negatively correlated to this principal component. These correlations correspond to a work behavior that is predominantly oriented towards focused individual work, with periodic coffee breaks, potentially accompanied with informal discussions. In addition, individuals who adhere to such work behavior spent most of their time in their offices, and this might explain the strong correlation with the standard deviation, and the negative correlation with the frequency of interruptions caused by them. Therefore, we will refer to the participants with such space usage behavior as *Workers*. Upon further analysis of the mean individual scores for this principal component, we observed that individuals with higher scores were mostly engineers, architects, and researchers, who also belonged to the group of Habituals.

Collaborators

Finally, the *Collaborators*, an interpretation that we attributed to the *third* principal component, exhibited a behavior pattern that is typical of people who participated in many formal meetings. The correlations with the time spent in the meeting rooms and the frequency of transitions within the building indicate the need to coordinate with several teams. Moreover, a negative correlation was observed with the time spent in colleague's office. One possible explanation for this could be the lack of meeting infrastructure within normal offices, such as projectors, and the capacity to accommodate several people. In addition, conversations within offices are often disturbing for individuals who are not participating in the meeting. The mean individual scores for this principal component also revealed that professors and project managers had relatively

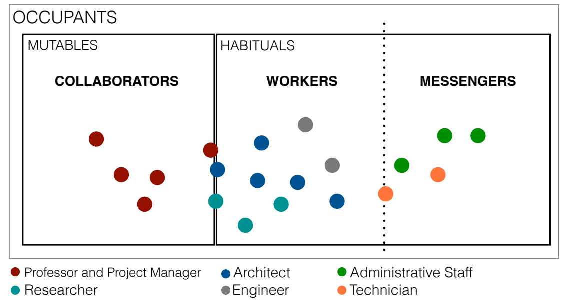

Figure 6. The distribution of the different professional profiles into the emerged space usage classifications.

higher scores, and these professional profiles also belonged to the aforementioned set of Mutables.

The results from PCA demonstrated a clear division in the space usage styles amongst the participants. On the one hand, the behavior of Messengers and Workers exhibited a further partition in our visually marked set of Habituals, as shown in Figure 6. On the other hand, the space usage behavior of Collaborators revealed new information about the set of Mutables. In addition, the professional profiles of the participants were shown to influence the space usage behavior. This finding might sound apparent, but it is important to note that each principal component corresponds to more than one professional profile. However at a higher level of granularity, the commonalities in certain variables that are shared by a specific set of professional profiles define their space usage behavior.

Predicting Professional Profiles

We used the logistic regression to evaluate the significance of previously suggested relationship between the process variables and the participants' professional profile, as reported in the post-study questionnaire. The model was found to be statistically significant (χ^2=57.58, p<.001, Pseudo-R^2=0.426, n=150), and four (out of eleven) process variables were found to significantly distinguish one profession from another. These variables mainly concern with the scope of mobility within the building (number of unique rooms visited and interrupted), the need for coordination with the others (or frequency of interrupting others), and the amount of time spent during breaks or informal meetings in the cafeteria.

Upon sharing the results of PCA and the interpretation of profiles with Studio A and Lab B, we brainstormed on the various design implications that they may provide to enhance the user experience. Moreover we revisited the objective of intensification of space, which led us to the need to assess the total and per-profile occupancy rates. This defined another iteration of data analysis which we present in the next section.

PHASE V. ANALYSIS OF OCCUPANCY RATE

In order to compute the occupancy rate, we excluded the spaces of public nature such as the cafeteria, the atrium, and the meeting rooms, because they were also used by other inhabitants who were not participating in our study, such as the visitors. The mean occupancy rate for a room during a day can be defined as the ratio of number of individuals who were present in the room to the maximum capacity of the room identified by the number of available desks. The number of individuals co-present within each office was computed from the space usage data for each 10-second time-window from 08:00 to 17:00.

The results showed that the mean occupancy rate for seven offices during the course of our study was 20.18%. The minimum rate for an office was observed to be 1.34%, which was solely occupied by two Collaborators (Mutables). The maximum density of 34.98% was witnessed for an office of two individuals, belonging to the class of Messengers (Habituals). In a more mixed environment, an office inhabited by two Collaborators, three Workers, and one Messenger, the mean occupancy rate was 30.58%.

The interpretation of principal components suggests that the different emerged profiles contributed differently to the total occupancy rate, with the Workers at the top, and the Collaborators at the bottom of the list. Since some of the participants were at the border of two profiles, the exact contributions are not quantifiable.

PHASE VI. IMPLICATIONS FOR DESIGN

Our results revealed three space usage patterns which correspond to different professional responsibilities. The Workers (researchers and engineers) spent a significant amount of their time inside their own office with occasional visits to the cafeteria. The Collaborators (professors and project managers) were the dominant users of the meeting rooms and demonstrated higher mobility and less dependence on their personal office spaces. The Messengers (administrative staff and technicians) transited frequently between different spaces to coordinate projects, while being anchored to their personal workspace. In addition, our results showed strikingly low overall occupancy rates, with different amount of contributions from these three profiles.

In this section, we describe some of the ways in which these results can translate to contextualized design implications that serve our first objective of space intensification while potentially improving the indoor user experience. The design suggestions that we explain next, were a subject of discussions with Studio A and Lab B. The first and the sixth are going to be implemented immediately, and the second one in the next building cycle.

1. Personal Space Adjustment. The Messengers were observed to be often interrupted, while focused individual work in their office was a significant part of their daily schedule. Interior architects can equip messengers' offices with ad hoc furniture that can allow for privacy adjustments. Such design measures can enable the communication and appropriation of visitation times, as well as facilitate an improved working experience. Such design can be coupled with an ambient awareness system and mitigate many of the problems that intensified work spaces may cause for the Messengers.

2. Shared Workspaces. The Collaborators, owing to their habit of mobility and their access to portable resources (laptops), are more open to the idea of desk sharing as compared to the Workers and Messengers. This can be an opportunity to integrate co-working places in the office building while considering the specific preferences of Collaborators. Such a setup can be one of the strategies to intensify the space instead of allocating a fixed workspace to everyone.

3. Reallocating Offices. The Messengers frequently visited other offices and were also interrupted in their office by the others. This necessitates the identification of individuals with such a behavior, and the reallocation of office spaces so as to minimize the distance covered to and from them. Furthermore, in longer term, their offices can be positioned in a way that affords for increased accessibility and communicability.

4. Spontaneous Social Interactions. The Workers were the frequent visitors of the cafeteria. However, due to the unpleasant design of the cafeteria space, as stated in the interviews, Workers' purpose in the cafeteria was limited in extent and solely afforded for the take-away of beverages and food. On the other hand, Workers as compared to Messengers and Collaborators had less opportunities for social interactions (formal and informal meetings). Therefore, a more inviting cafeteria space confirming with the expectations of Workers can catalyze spontaneous inter-personal interactions.

5. Recurrent Rapid Space Occupancy Assessment. During our study, the average occupancy rate in the office spaces was observed to be considerably low. This stresses on an opportunity for making positive impact on the space utility, and hence a significant step towards sustainability. One way to achieve this goal is to iteratively examine new space reconfigurations in specific parts of the building. The impact of each trial on occupancy rate can be rapidly assessed by our method.

6. Rethinking Meeting Rooms. The meeting rooms were often overbooked, and thus did not allow for spontaneous meetings, as stated by the participants during interviews. In addition, due to the lack of spaces for smaller meetings (2-3 participants), the large rooms were sometimes used by smaller group sizes. This is an example of unsustainable space organization that also offers poor user experience. One possible solution is to integrate small acoustically insulated spaces within larger offices to enable their occupants to have spontaneous agile meetings without occupying the designated meeting rooms. In addition, these meeting spaces can assimilate the affordances of co-presence to support the need for collaboration beyond the office (i.e. remote collaboration and work-from-home).

DISCUSSION & FUTURE DIRECTIONS

Scalability and Generalizability

Considering the low-cost and rapid technical setup that our data collection method requires, it can be scaled for larger buildings, higher number of occupants, longer duration of study, and various types of buildings such as homes, libraries, museums, etc. The duration of the study, however, if integrated into an architectural project, might be constrained by the overall time plan. Also, adopting this approach for public buildings might pose logistical challenges in terms of distribution and collection of sensors from the visitors.

The case study presented in this article is a proof of concept for the method that we examined (i.e. the sensing system coupled with the iterative participatory data analysis). This method furnishes the researchers and designers in HBI with a versatile tool that is transferable to a diverse set of situations and contexts. The results, however, are reported without aspiring to be generalizable to other buildings, because of numerous variations in space topology, population, and organizational structure. Even for a specific context of office building, a larger population of similar studies is needed to be able to create reliable knowledge about possible space usage patterns.

As noted previously (in Phase II), we addressed the concerns related to research ethics and perception of privacy, by the means of transparent communication and building trust with all the participants in the briefing session. This, we believe is crucial, primarily in order to retain the ethical values, and secondly to maximize the participation willingness and consequently the validity of collected data. Nevertheless, the trust building method that we examined in the presented case study might not be generalizable to the study of public buildings where a larger population is monitored in relatively ephemeral sessions. It goes beyond the scope of this contribution to comprehend the factors that can have impact on the perception of privacy. For example, one can argue that, compared to seamless data collection tools (e.g. motion capture cameras), wearable devices may be perceived less privacy-intrusive, because the participants have the full control on where and when to be or not to be monitored.

The Stiffness of Architecture

Considering the expanding engagement of HCI in the design of new digital artifacts that include physical embodiments, it is natural to conceive that HCI will enter the domain of our computerized physical environments, including the domain of building design [9]. Moreover, with the legacy of HCI in collaborating with artifact and interaction designers, its integration into other design domains (such as architecture) ostensibly can follow a similar approach. However, in our experience of taking part in a building design project, we were confronted with a set of challenges that we explain as the “stiffness of architecture”. The process of building design is a project with a highly rigid time schedule, constrained resources, and defined objectives. The long expected life-span of buildings often does not leave space for risk-taking or examining new functions and forms. Also, in the ideologies of architecture, most of the decisions are made before the construction starts and any later modification, especially after the occupancy, is referred to as “superficial interventions” (despite the unfolding critics and movements for flexibility [33]).

These stem from numerous reasons and lead to a situation where the integration of new tools and methods becomes practically challenging. Nevertheless, we argue that exactly this stiffness requires an iterative participatory strategy: iterative, to frequently exchange results and to be able to have an impact when the moment is opportune; and participatory, to create the indispensable atmosphere of mutual awareness about the complete repertoire of the project domain. What we could achieve through such strategy manifested itself in informing the recurrent question of which design alternatives should be appropriated to which group of occupants. This, we believe, is the responsibility of the HCI research, and would have been impossible without the complete fusion of user studies into the architectural project.

Actors, Activities, Spaces, and Artifacts

The state of occupancy within built environments contains plentitude of contextual information that can be analyzed from multiple perspectives. Amongst these, the viewpoint of *actor*, *space*, and *activity* held special relevance for us and thus propelled our analysis forward. Inhabiting different spaces as well as the mobility within the building from one room to another is informative of occupants’ activities. This is particularly true in office buildings, where the relationship between spaces and activities are more explicit (as compared to, for example, home buildings). The office spaces for focused individual work are well defined and delineated, and certain spaces are designated for formal and informal social activities. This strong coupling between the space and associated activity facilitated our analysis of inhabitants’ work routines, as well as the interpretation of the kinds of activities they performed in different spaces.

However, we believe that a more complete study of space entails the incorporation of the element of *artifact*. Understanding how occupants utilize and interact with artifacts such as office furniture can provide more reliable and fine-grained information about their interactive experience with(in) the built environment. This is guiding our upcoming study, where we will integrate a set of sensors into the furniture that is being designed by Studio A to enable personal space adjustments.

CONCLUSION AND FINAL WORDS

With the strong belief that HCI can and should engage in the design of our built environments, we took a concrete step and tried to integrate the human-centered methods and approaches into a post-occupancy architectural project. We believe that the contributions of this endeavor go beyond the creation of a scalable method for space use evaluation. An essentially more valuable achievement was to demonstrate the intricate variances in how we experience spaces, which without user studies would have remained invisible. The result of this work has convinced the stakeholders about the effectiveness of HCI tools, and the value in continuing this collaboration for the upcoming cycle of the building, which will be more expansive in terms of physical space, population, as well as inclusion of residential spaces.

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