

# Understanding Behavior with Ubiquitous Computing for Architectural Design

By

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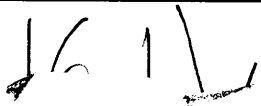
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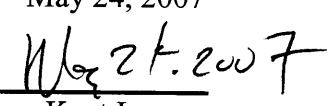
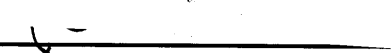
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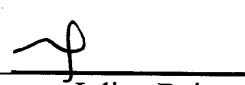


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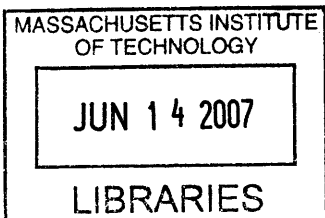
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## ABSTRACT

Understanding the relationship between workplace environment and behavior is an important concern for designers. We report on a pilot study where ubiquitous computing was used to examine workplace activity quality in a commercially designed workplace environment. Data were collected from twelve adult participants in the same professional workplace, for twenty-one workdays during one month. The data collection system was composed of small wireless infrared motion sensors, a Bluetooth-based positioning system using mobile phones, and a context-sensitive self-report survey administered on the mobile phones. Participants were automatically queried about their work practices and their environment via these mobile phones, every time they changed their locations in the workplace. Questions were also asked during the remainder of the day, albeit less frequently. We describe how software visualization tools were developed to visualize the data collected during the experiment, and we report on some of the attributes of subjects' behaviors that can be observed using the tools. Implications of these results with respect to research methods and enabled design methods are discussed.

Thesis Supervisor: Kent Larson  
Title: Principal Research Scientist



## TABLE of CONTENTS

|                                |    |
|--------------------------------|----|
| Introduction                   | 9  |
| Background                     | 13 |
| Prior Work                     | 16 |
| System Design                  | 17 |
| MIT Environmental Sensors      | 17 |
| Bluetooth Positioning System   | 18 |
| Experience Sampling System     | 18 |
| Software                       | 18 |
| Method                         | 21 |
| Participants                   | 21 |
| Constructs and Measures        | 22 |
| Procedure                      | 27 |
| Compliance                     | 28 |
| Results                        | 30 |
| Data Visualization             | 30 |
| Factor Analysis                | 41 |
| Discussion                     | 47 |
| Future Work                    | 42 |
| Evaluating Finished Work       | 51 |
| Evaluating Prospective Designs | 54 |
| Generative Design Tools        | 54 |
| Appendices                     | 55 |
| References                     | 77 |



## INTRODUCTION

The notion that designed environments have an effect on the behavior of their occupants is widely assumed in architectural and design practice,<sup>1</sup> but there appears to be little industry agreement on methodology for implementing occupancy studies.<sup>2</sup> Furthermore, the literature on the topic of occupancy evaluations mostly consists of small scale studies that are specifically designed for one group of subjects in one building, and are not designed experimentally such that they may work in many different types of environments.<sup>3</sup> In the past few decades, technology has made it possible to efficiently measure the ambient environment (i.e. temperature and humidity levels, light levels, sound levels, etc.), to establish functioning conditions while the environment is being used, over extended periods of time. However, designers still have few tools for measuring the effect of an environment on human psychology, cognition, and behavior. A thorough search of the IEEE and ACM electronic databases revealed only one publication on behavioral assessment for architectural design.<sup>4</sup>

Conventional methods of environmental evaluation are typically designed to explicitly provide answers to a set of generalized questions, instead of providing a perspective on overall behavior that allows designers to then ask pertinent, specific questions, as would be necessary to gain a holistic perspective on user behavior. Furthermore, it is clear that conventional means of collecting this type of data – one-time questionnaires or surveys – produce results that do not correlate well with real time empirical data regarding the same behavior or events.<sup>5</sup>

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<sup>1</sup> “The events of human life, whether public or private, are so intimately linked to architecture that most observers can reconstruct nations or individuals in all the truth of their habits from the remains of their monuments or from their domestic relics.” (Honore de Balzac); “We shape our buildings; thereafter they shape us.” (Sir Winston Churchill)

<sup>2</sup> Please see Appendix A for a list of reviewed occupancy evaluation systems.

<sup>3</sup> In terms of the latter, there are attempts (BUS and CBE) to implement questionnaires on a large scale, but such studies have yet to come to fruition.

<sup>4</sup> Yan & Forsyth, 2005

<sup>5</sup> This is not to undermine the relevance of qualitative data – only to point out the distinction when considering such data when it addresses quantitative behavioral phenomena.

A notable body of research has emerged in the past few decades, in the psychology literature, suggesting methodologies for empirical assessment of the interaction between an environment and human behavior (e.g., *Journal of Environment and Behavior*). These studies show that environmental conditions are a significant factor in human behavior and cognitive performance,<sup>6</sup> as well as other psychological<sup>7</sup> and physiological dimensions.<sup>8</sup>

Studying human behavior and the environment may reveal relationships that are useful in architectural design. For professional architects, “designing with the behavior of the occupants in mind” is often a significant part of the work process. Design justifications therefore often involve intended behavior of occupants (i.e. spatial layout affecting interaction between research groups). However, many of the small portion of existing, mainstream occupancy analysis studies that include behavioral dimensions, with surveys and ethnographic tools, are subject to investigator and response bias, and are very costly (i.e. requiring long term observation). An aim of this thesis is to expand the field of occupancy evaluation so that architects and designers have tools that enable them to measure the impact of a design on behavior.

Designers currently have few cost-effective tools to gain an empirical understanding of the effect of architectural design on user behavior. The problem is that conventional methods of assessing the behavior of users in existing, occupied architecture, for the purpose of designing a new space, are time consuming (and therefore costly), and invasive for occupants (i.e. direct observation), or rely solely on user retrospective assessment, which has been shown to conflict with data on actual behavior.<sup>9</sup> Due to the difficulty of deploying these tools, designers are not compelled to evaluate new designs in terms of user behavior, after they are built.

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<sup>6</sup> Cimprich, 1990; Hartig, Mang, & Evans, 1991; Kuo, 2001; Tennessen & Cimprich, 1995

<sup>7</sup> R. Kaplan, 1973

<sup>8</sup> For example, it has been shown that surgical patients in rooms with windows with specific views showed benefits, including shorter postoperative hospital stays, and requiring fewer potent analgesics, as opposed to patients in similar rooms, but with windows with a specifically different type of view (Ulrich 1984).

<sup>9</sup> Stone, Shiffman, Schwartz, Broderick, & Hufford 2002

During the past several decades, a small body of psychology literature has illustrated that environmental factors have profound effects on human psychology. Demonstrated environmental associations include psychological well-being,<sup>10</sup> cognitive functioning,<sup>11</sup> and physiological condition.<sup>12</sup> Workplace environments have been a focus of some such research, due to implications for productivity and profitability. Although this research has examined the direct effects of certain physical design characteristics on humans, such as presence of windows<sup>13</sup> or indoor plants,<sup>14</sup> factors such as interactions with others (i.e. group meetings) and quality of work activity have not yet been measured.

In this work, we demonstrate how the technologies of mobile devices and sensor networks might be used to study and evaluate the behavior of people in architectural environments. The availability and cost of these devices is dropping rapidly, and mobile devices can gather and analyze information from sensors in the environment in real-time. Phone processing power, memory, data connectivity, and battery life is all improving, as well as their sheer ubiquity (i.e. current conservative estimates are that over 60% of all people in the United States carry a mobile device).<sup>15</sup> The former makes them suitable for powerful context aware applications, where services and functions can rely on estimates of where the user is and what the user is doing. The latter creates the opportunity to use the phone to gather sensor and self-report data continuously, for extended time periods, wherever people go.

This document presents a ubiquitous computing based automated occupancy analysis system. An empirical study utilizing this automated system is then presented,

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<sup>10</sup> R. Kaplan, 1973

<sup>11</sup> Cimprich, 1990; Hartig, Mang, & Evans, 1991; Kuo, 2001; Tennessen & Cimprich, 1995

<sup>12</sup> E. O. Moore, 1981; West, 1986; Ulrich, 1984; Verderber, 1986; Verderber & Reuman, 1987

<sup>13</sup> Leather, Pyrgas, Beale, & Lawrence, 1998

<sup>14</sup> Larsen, Adams, Deal, Kweon, & Tyler, 1998

<sup>15</sup> <http://www.itu.int/ITU->

[D/icteye/Reporting/ShowReportFrame.aspx?ReportName=/WTI/CellularSubscribersPublic&RP\\_intYear=2005&RP\\_intLanguageID=1](http://www.itu.int/ITU-D/icteye/Reporting/ShowReportFrame.aspx?ReportName=/WTI/CellularSubscribersPublic&RP_intYear=2005&RP_intLanguageID=1)

examining the relationship between workplace environment and real-time reported job activity quality. The main contribution of this work is the demonstration that ubiquitous computing tools can effectively and economically collect data about human behavior in relationship to environments. Further, this data can be structured through visualizations in a way that provides designers with the ability to determine what is important, from a very large space of possible features in the data, by focusing on the meanings of visual features in a graph.



## BACKGROUND

The most prevalent behavioral occupancy evaluation methods currently in use are survey based methods of providing designers with material that allows them to better understand a given design problem.<sup>16</sup> They give subjects a one shot chance to provide input about the whole of their work activities, through a set of questions that require subjects to generalize about their behavior. An option that is sometimes included in these reviews includes direct observation, whereby a member of a consultant staff sits and observes the clientele for lengthy periods of time. This is clearly a very expensive proposition, yet its inclusion in the process indicates the need to collect information that cannot be gained through conventional surveys. Designers understand that there is a need to understand user behavior beyond their own generalizations. We have implemented automated, mobile device based experience sampling system to accomplish this at a fraction of the cost of direct observation, by automatically prompting subjects to quickly register the nature of their activities throughout the day, for an extended period of time. This type of “just-in-time” experience sampling has the capability of capturing a temporal and, with our systems, a spatial layer of data with similar qualitative dimensions.

We propose a system that relies on the ubiquity of mobile devices (i.e. phones). In doing so, we also propose that this type of system has the potential to become ubiquitous, itself. Commercial development is already underway, for systems that take advantage of context awareness to provide services (i.e. location based advertising, product tracking, transportation services tracking). Proof of concept is provided by the Google Maps application, which provides users with the ability to locate nearest public transportation units (taxis / buses / subway trains), and other geospatial web services, where media is tied to location, which is resolved through any number (often a combination) of means. At the heart of this is the notion that "when you look at [any] object [or location], you can [access] the information that [anyone] has added to it" - a sort of world-as-wiki model. At the personal level, these systems enable applications that are aware of the users' locations relative to other users or objects, and a myriad of services that attempt to answer the

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<sup>16</sup> i.e. Steelcase Community Based Planning (CBP)

question – “what kinds of tools can help [the user] to be more creative / more productive / improve my health?”

Every such application can individually contribute to the ubiquity of mobile devices. Many rely on specific technologies embedded in these mobile devices, that in turn enable other types of applications to become widespread (i.e. because the devices will already exist, for other purposes). At the most basic level, such ubiquity can allow idle processing power of remote devices to be utilized for generalized behavior research that can be applied towards the design of environments (while providing context aware services to the individual users). Higher level applications include building systems (environmental controls, industry safety monitoring equipment, mobile medical, etc.) integrated with such behavioral information. In other words, the end-user applications proposed by service providers allow low power/cost mobile sensing equipment to gain ubiquity, which results in economical means of introducing powerful macro-behavioral applications (i.e. traffic control, automated large scale wireless package inventory, etc.). The promise of these types of solutions for architectural means will be discussed in this document.

Combined with localization technology, ubiquitous mobile computing technology is armed with the ability to generate usefully interactive environments. This is partially owed to the fact that people now carry mobile devices virtually continuously. Various localization or positioning technologies are becoming increasingly supported by cellular phone systems. This functionality may be extended to include public services; such as the ability for users to place common services requests. Access permissions may then be determined by the host environment, according to whatever criteria may suffice. As such, interaction and controls are an aspect of architectural environments that many consider to be vastly underutilized – however, when everyone has a remote control, this opens up a new range of possibilities.

In terms of privacy, one must address the effect of the continual recording of individuals’ physical experiences in the digital world, with the possibility of being

accessed, browsed, and mined. An answer might be seen in the nature of web logs (blogs), which few predicted would become as ubiquitous as they are, today. It might be argued that the primary purpose of such journals is for the author himself/herself; secondarily, it serves as a mode of communication to the author's closest social circle. The day to day use of the information presented is up to the imagination and needs of society, as individuals are empowered with the perceived freedom to decide who can access the information. The speed at which web logs have attained ubiquity is, perhaps, proof of the ability for users to find function to maintaining a digital record of their lives.

A useful metaphor might be to think of physical experience, or "browsing the world" as "browsing the web." As such, individuals can maintain a history, set location based reminders, with all of the functionality of web cookies, monitor their own behavior, explore their environment, keep accessibility settings, store personal profiles, and maintain the ability to control access to the wealth of information that becomes possible.

An interesting and architecturally relevant aspect to the paradigm of a "world wide web of existence" – is related to the vast body of research on the structure of the internet and browsing behaviors of its users. We can only begin to imagine a design world wherein we can apply a holistic understanding of peoples' activity throughout the urban environment, in the same way that software architects and computer science researchers are beginning to address the problems of human computer interaction.

## PRIOR WORK

Prior work has been conducted with occupancy recognition with similar distributed sensing equipment, including testing of high level behavior recognition algorithms (i.e. meetings, fire drills).<sup>17</sup> This has also been attempted as a computer vision application,<sup>18</sup> using video, but there exists a strong ethical and economical argument for utilizing equipment that provides only the bit level information that is required of the system. The ethical argument rests on the assumption that people perceive the vulnerability of a system to abuse, whether or not they have reason to believe that it is being abused.<sup>19</sup> Therefore, simply having devices with clear optical lenses (as opposed to the opaque lenses on our PIR MITes) presents itself as a perceived intrusion. The economical analysis of the problem of occupancy sensing by Reynolds and Wren concludes that a system that offers one bit of information per square meter per second is ideal.<sup>20</sup>

Prior to this work, no such ubiquitous computing based occupancy research has included experience sampling, to collect information on users' perceived qualities of activities.

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<sup>17</sup> Munguia-Tapia & Wren, 2006

<sup>18</sup> Yan & Forsyth, 2005

<sup>19</sup> Reynolds, 2005

<sup>20</sup> Reynolds & Wren, 2006

## SYSTEM DESIGN

Two types of data were collected – quantitative low level occupancy data, and qualitative high level workplace quality data. The first data type includes information regarding the presence of individuals throughout the space, as well as their movement patterns. There are three interdependent systems involved – MIT Environmental Sensors (MITes),<sup>21</sup> a Bluetooth Positioning System (BTPS), and an Experience Sampling System.



Figure 1: Equipment

### MIT Environmental Sensors

The MITes system is a distribution of motion sensors that simply logs the presence of users throughout the space (appx. 6' x 6' resolution). The choice of MITes is based on low cost, relative to other commercially available sensor systems, and high scalability of system structure and performance.

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<sup>21</sup> developed by the Massachusetts Institute of Technology House\_n Research Consortium

## Bluetooth Positioning System

The BTPS system is a distribution of passive beacons that allows users' mobile devices to perform a positioning routine which is based simply on the IDs of available beacons, with a variable resolution that can be adjusted (from appx. 100' x 100' to appx 10' x 10' resolution). The development of the Bluetooth Positioning System was driven also by cost, relative to other commercially available indoor positioning systems, as well as the need for a system that worked at the resolution of typical work spaces (i.e. appx. 10'x10').<sup>22</sup>

## Experience Sampling System

The previous systems allow real time recognition of movement behavior. Shortly following a subject's move from one space to another, he/she will be queried via his/her mobile device, concerning the nature and quality of the activity that just took place. As such, the experience sampling data will be collected using software deployed on the phones, which primarily takes advantage of the BTPS data for context sensitive functionality.

## Software

All software applications for mobile phone positioning, experience sampling, data collection (intranet MITes data collection and internet transmission to a local server), and data visualization were written by the author in the C# language. This decision was based on the need for interoperability with existing support infrastructure (computers and networks to host data collection applications).

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<sup>22</sup> For example, GPS does not function indoors, and Cricket systems have higher resolution than necessary for room level positioning, and are extremely costly. Our Bluetooth based system relies on standard hardware mobile devices.

We have developed a questionnaire system that allows subjects to quickly register the nature of their activities throughout the day, for an extended period of time. This type of “just-in-time” experience sampling has the capability of capturing a temporal and, with our systems, a spatial layer of data with similar qualitative dimensions. Through user testing, we developed the following set of queries, which are designed to be prompted on a mobile phone:

Table 1: Questionnaire

| ID      | Question  | Response Scale (Likert)   |
|---------|---|---|
| Q04     | "Did you feel that, during this time, your environment accommodated your needs?"                                  | 1 = "no, the environment made things difficult" → 4 = "yes, the environment met my needs perfectly" |
| Q05     | "How much of this time involved independent activity, versus group activity?"                                     | 1 = "all independent" → 4 = "all group activity"  |
| Q06**   | "How much of this group activity involved presentations?"   | 1 = "none" → 4 = "all"  |
| Q07**   | "How much of this group activity was virtual (involved electronic communications, including messaging or email)?" | 1 = "all virtual" → 4 = "all in person"   |
| Q08**   | "During this time, did you brainstorm?"   | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q09**   | "My activity during this time was mainly?"  | 1 = "work" → 4 = "social"   |
| Q10***  | "During this time, did you do any writing tasks (by hand or on a computer)?"                                      | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q11***  | "For your activities during this time, did you need to be isolated?"  | 1 = "no, anyone could have taken part" → 4 = "yes, I needed to have my own space"                   |
| Q12***  | "During this time, did you do any analytical or design tasks?"  | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q13***  | "During this time, did you do any organizing of your digital or physical space?"                                  | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q14***  | "How well could you concentrate during this time?"  | 1 = "not well at all" → 4 = "very well"   |
| Q15**** | "During this time, how effective was communication between people?"   | 1 = "not effective at all" → 4 = "very effective"   |
| Q16**** | "Did you learn much?"   | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q17     | "How did your activity, during this time,   | 1 = "decreased stress" → 4 = "increased"  |

|     |   |   |
|-----|---|---|
|     | affect your stress levels?"   | stress"                                       |
| Q18 | "During this time, did you accomplish much, in terms of your individual tasks?" | 1 = "no; none" → 4 = "yes; lots"              |
| Q19 | "Are you more or less energized for future tasks?"                              | 1 = "not energized" → 4 = "very energized"    |
| Q20 | "How valuable was your activity, during this time, to you?"                     | 1 = "a waste of time" → 4 = "highly valuable" |

\*\*if (response[Q05] > 1)

\*\*\*if (response[Q05] < 5)

\*\*\*\*if (response[Q05] > 1)



## METHOD

Two types of data were collected in the data acquisition phase – quantitative low level occupancy data, and qualitative high level social network data. The first data type includes information regarding the presence of individuals throughout the space, as well as their movement patterns. There are two main systems involved – MIT Environmental Sensors (MITes), and a Bluetooth Positioning System (BTPS). These systems allow real time recognition of movement behavior. Throughout the study period, shortly following a subject's move from one space to another, he/she was queried via his/her mobile device, concerning the nature and quality of the activity that just took place. As such, the second data type was collected using software deployed on the phones, which takes advantage of the first data type for context sensitive functionality.

Acquiring this data raises serious privacy concerns, which are dealt with through the technology implementation. The MITes collect data without identity; the BTPS system does record collect identity information, but the positioning routine is performed entirely on the users' device, so individuals will always have the option of turning this system off. It is predicted that the utility of these location aware systems will ultimately compel users to leave the system on, in the future.

### Participants

A total of twelve adults<sup>23</sup> participated in this study. All were working professionals in the same working group at the corporate headquarters office building of Steelcase in Michigan. All are working peers of similar job status and socioeconomic status. Eleven of the twelve participants were designers, and one was an engineer. Two of the designers, as well as the engineer, had a managerial role that did not preclude their role as designers/engineer; these three subjects collaborated with the rest of the subjects on projects, in the same sense that most subjects collaborated with each other on projects.

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<sup>23</sup> six males, six females

MIT institutional review board approval, for use of human subjects in research, was obtained, for this study.<sup>24</sup> All participants were volunteers, with an incentive that they would be able to use and keep the mobile phones that were part of the study. The length of time commitment for the subjects was one month. Participants were informed that they could exit the study without penalty at any time, due to discomfort or concern about the data collection. No participants actually exited the study.

### Constructs and Measures

Occupancy. 120 PIR MITes were installed on the ceiling, throughout the study area. Each provided information on whether or not a person occupied the circular area below the sensor, roughly two meters in diameter. As a whole, these provide data on the duration and frequency of use of each space within the study area.

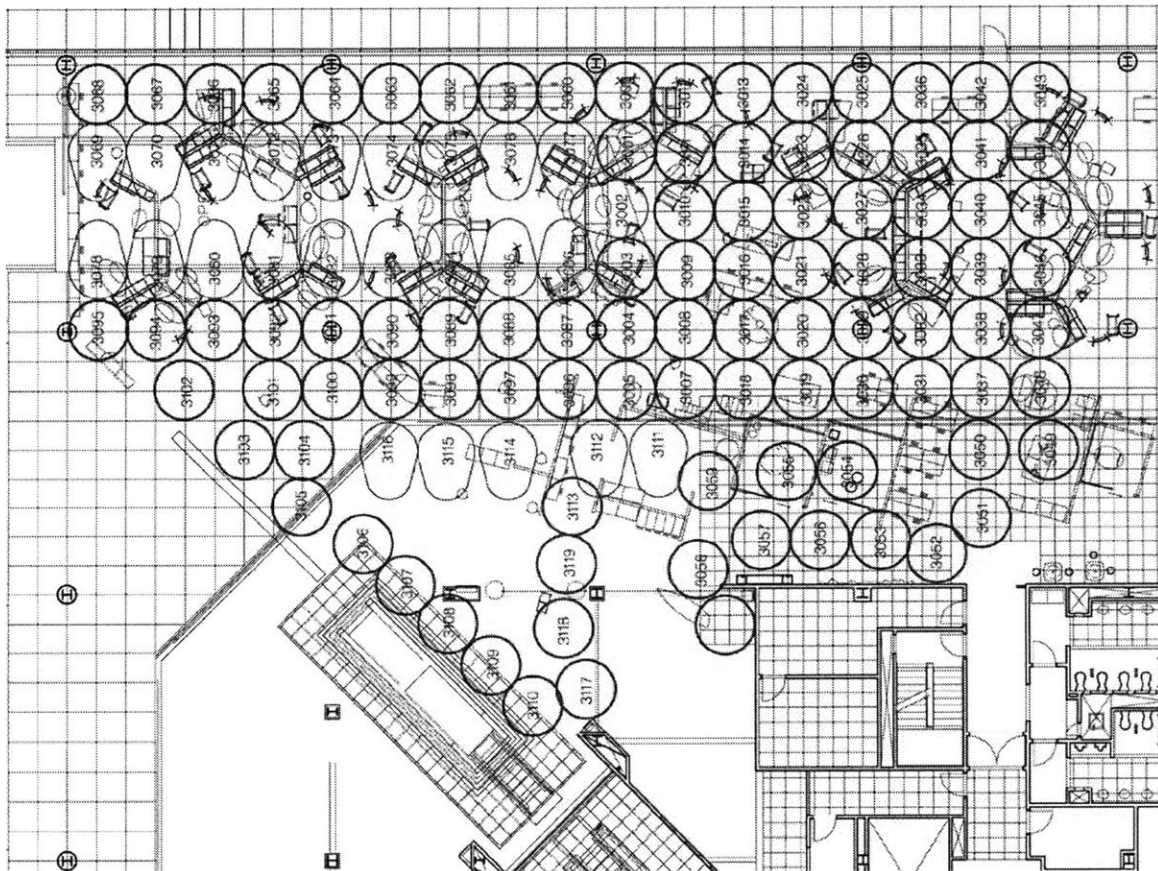


Figure 2: PIR MITes sensor locations

<sup>24</sup> COUHES Protocol # 0703002146

Environment Type. Prior to data collection, each space in the study area was labeled by type (personal work space, meeting area, or lounge area) as according to design intent. The mobile device positioning system employed in the study automatically recorded location data such that all questionnaire data was automatically associated with an environment type.

Table 2: Environment Types

| <b>Low Level Categorization</b> | <b>High Level Categorization</b> |
|---------------------------------|----------------------------------|
| Personal work space (window)    | Personal Work Space              |
| Personal work space (edge)      | Personal Work Space              |
| Personal work space (interior)  | Personal Work Space              |
| Personal work space (hall)      | Personal Work Space              |
| Meeting area (open)             | Meeting Area                     |
| Meeting area (closed)           | Meeting Area                     |
| Lounge area (café)              | Lounge                           |
| Lounge area (seating)           | Lounge                           |
| Lounge area (media station)     | Lounge                           |

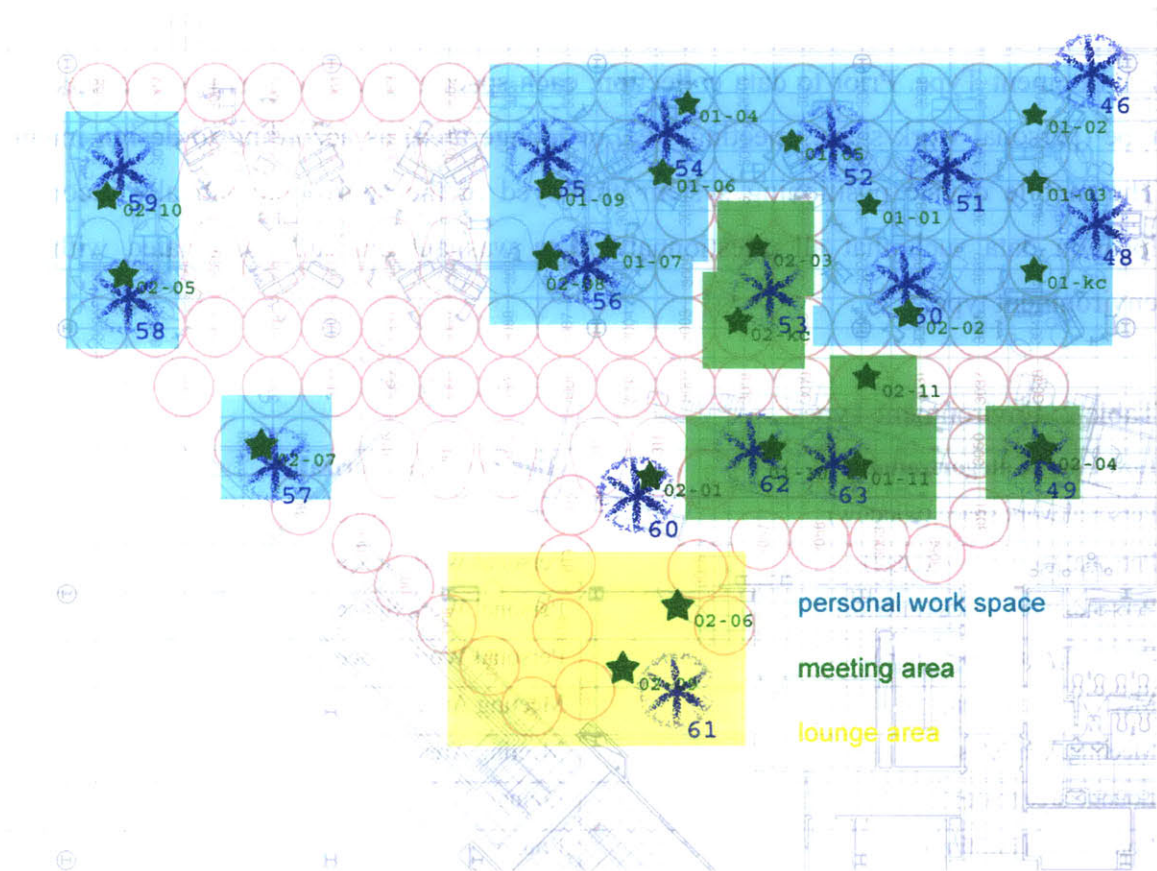


Figure 3: BTPS location recognition

Work Type. The questionnaire included characterization of activity by work type, according to seven items regarding the nature of the activity as independent or group oriented, involving presentations, involving virtual communication, work or social, involving writing tasks, needing isolation, involving analytical or design tasks, and involving organizing tasks. The work type scale items are summarized in Table 3.

Some of these questions specifically involved group or independent activities. In these cases, whether or not the question was asked in a given questionnaire session was dependent upon the subject's responses to earlier questions (i.e. if the subject reported engaging in only independent activity, then questions about the nature of group activity would be omitted). It would be expected that subjects' frustration with the system would increase without this conditional branching, as irrelevant questions may be seen as a waste of time.

Table 3: work type questions

| ID     | Question  | Response Scale  |
|--------|---|---|
| Q05*   | "How much of this time involved independent activity, versus group activity?"                                     | 1 = "all independent" → 4 = "all group activity"                                  |
| Q06**  | "How much of this group activity involved presentations?"   | 1 = "none" → 4 = "all"  |
| Q07**  | "How much of this group activity was virtual (involved electronic communications, including messaging or email)?" | 1 = "all virtual" → 4 = "all in person"   |
| Q09**  | "My activity during this time was mainly?"  | 1 = "work" → 4 = "social"   |
| Q10*** | "During this time, did you do any writing tasks (by hand or on a computer)?"                                      | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q11*** | "For your activities during this time, did you need to be isolated?"  | 1 = "no, anyone could have taken part" → 4 = "yes, I needed to have my own space" |
| Q12*** | "During this time, did you do any analytical or design tasks?"  | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q13*** | "During this time, did you do any organizing of your digital or physical space?"                                  | 1 = "no; not at all" → 4 = "yes; a lot"   |

\*if (response[Q01]=1)

\*\*if (response[Q01] != 1 && response[Q05] > 1)

\*\*\*if (response[Q01] != 1 && response[Q05] < 5)

Workplace Activity Quality. Of primary interest were characterizations of the quality of each work activity, according to nine items regarding the nature of the activity in terms of accommodation of needs, cognitive attention, ability to concentrate, communication effectiveness, learning, stress, accomplishment, energy, and overall value. The workplace activity quality assessment scale items are summarized in Table 4.

Table 4: workplace activity quality questions

| ID    | Question   | Response Scale  |
|-------|--|---|
| Q04*  | "Did you feel that, during this time, your environment accommodated your needs?" | 1 = "no, the environment made things difficult" → 4 = "yes, the environment met my needs perfectly" |
| Q08** | "During this time, did you brainstorm?"  | 1 = "no; not at all" → 4 = "yes; a lot"   |

|                    |   |   |
|--------------------|---|---|
| Q14 <sup>***</sup> | "How well could you concentrate during this time?"                              | 1 = "not well at all" → 4 = "very well"           |
| Q15 <sup>***</sup> | "During this time, how effective was communication between people?"             | 1 = "not effective at all" → 4 = "very effective" |
| Q16 <sup>***</sup> | "Did you learn much?"   | 1 = "no; not at all" → 4 = "yes; a lot"           |
| Q17 <sup>*</sup>   | "How did your activity, during this time, affect your stress levels?"           | 1 = "decreased stress" → 4 = "increased stress"   |
| Q18 <sup>*</sup>   | "During this time, did you accomplish much, in terms of your individual tasks?" | 1 = "no; none" → 4 = "yes; lots"                  |
| Q19 <sup>*</sup>   | "Are you more or less energized for future tasks?"                              | 1 = "not energized" → 4 = "very energized"        |
| Q20 <sup>*</sup>   | "How valuable was your activity, during this time, to you?"                     | 1 = "a waste of time" → 4 = "highly valuable"     |

\*if (response[Q01]!=1)

\*\*if (response[Q01] != 1 && response[Q05] > 1)

\*\*\*if (response[Q01] != 1 && response[Q05] < 5)

\*\*\*\*if (response[Q01] != 1 && response[Q05] > 1 && response[Q02] != 3)



## Procedure

All data were collected according to a uniform protocol summarized here,<sup>25</sup> using personal mobile devices. Each subject was given a device that automatically prompted them to respond to the questionnaire every time the subject changed location within the study area, as long as they spent longer than ten minutes in the previous location. This information, regarding when and how often subjects changed location, was automatically monitored by the BTPS system. When subjects were not in the designated study area, they were queried every two hours and asked about the type and quality of their activities, as long as they reported that they were working. In total, data were collected for 1803 activities; responses to the questionnaire were received 1803 times, amongst all participants, over the course of the month.



Figure 4: experience sampling application

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<sup>25</sup> Please see Appendix F for a description of the study protocol.

## Compliance

To ensure that subject's interactions with the query tool were as expected, compliance was monitored throughout the study. Figure twelve shows an example of total daily query compliance rate. Subjects were given the initial opportunity, with each query, to respond that they do simply not have enough time to respond to the query. These cases, when the subjects respond that they do not have time, as well as queries that were started but not completed within a reasonable amount of time (discussed further) are defined as user non compliance. Queries that were halted due to incoming phone calls are defined as interruption non compliance. Approximately 8% of all attempted queries were interrupted, and approximately 21% of all attempted queries were cancelled due to user non compliance.

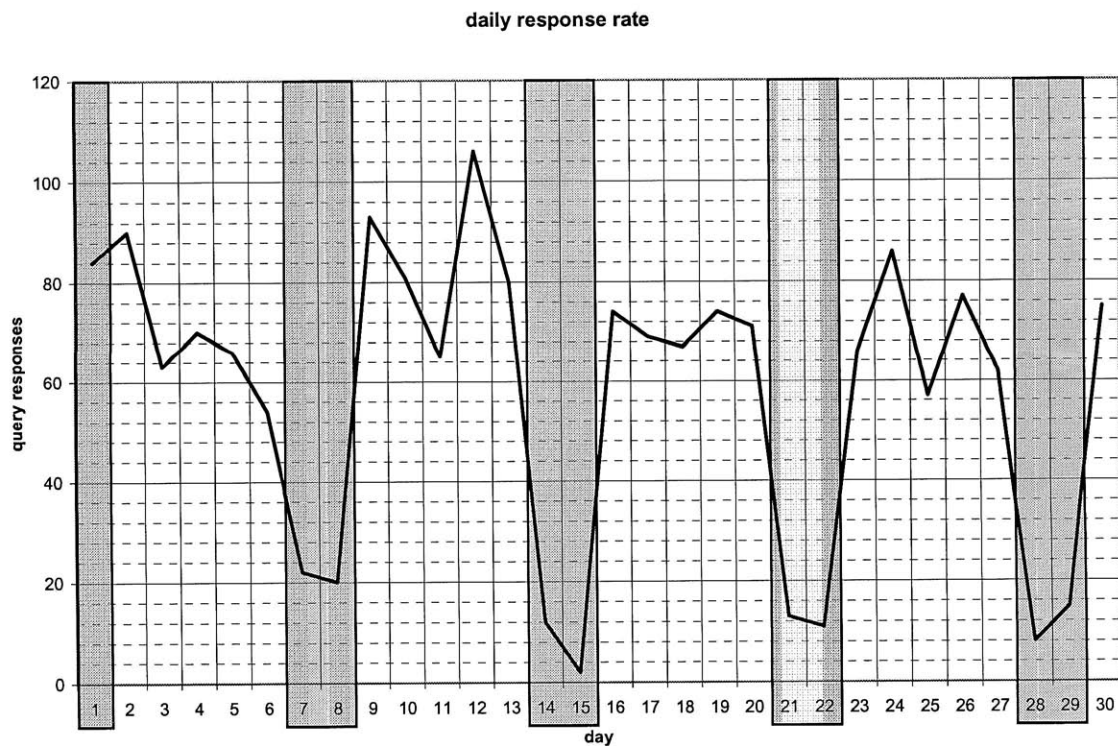


Figure 5: responses per day (weekend days are shaded)

As can be seen above, query response was significantly reduced on weekends. Note that full queries were only implemented when subjects reported having engaged in



work activities or were physically in the workplace – during the weekends, neither scenario occurred frequently enough to have statistically meaningful data for the weekends. Given the intuitive assumption that subject behavior is significantly different on weekends than work days, and the relative lack of data, week end data was removed from the data set before analysis.

The amount of time taken to complete a query (from subjects' input to stop the alert to completion of the last question) was also monitored. The vast majority of queries took less than five minutes to answer, with most taking between one and two minutes. As the study progressed and subjects became more acquainted with the system, mean response time decreased with most responses taking one to two minutes. The longest query response took over four hours – this, as well as the few other query responses taking longer than indicated by the ninety-fifth percentile (twenty minutes) were removed from the data before analysis.

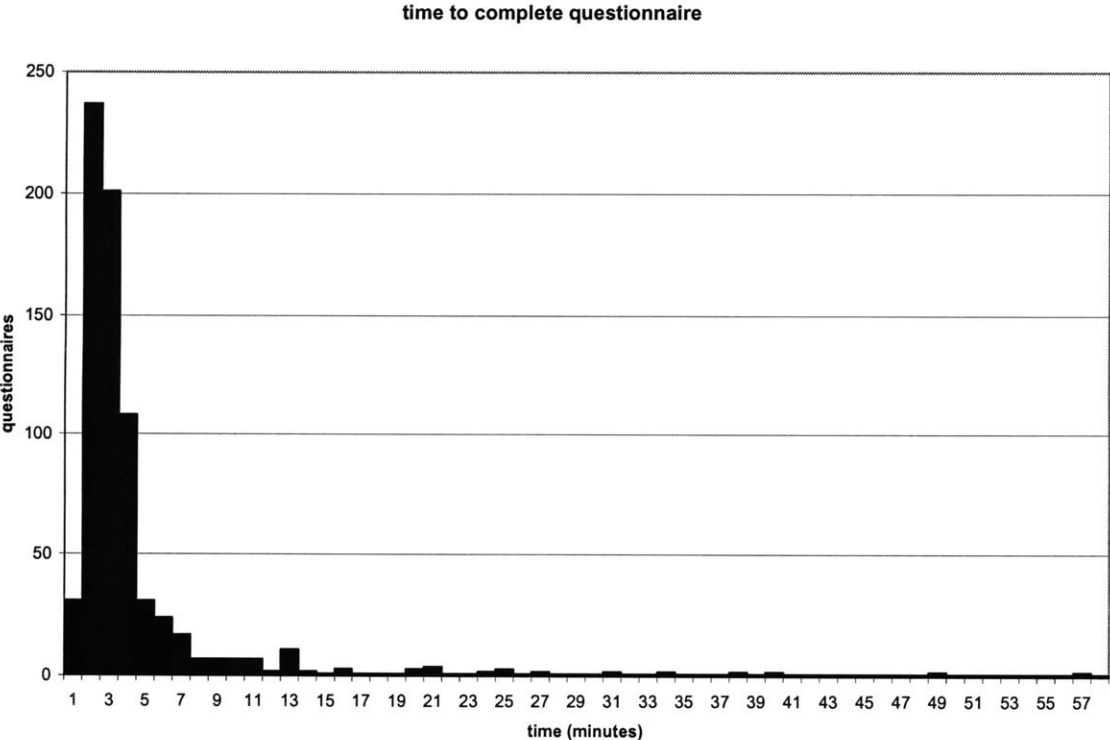


Figure 6: time to complete queries

Responses to the first question (Q00:"Do you have time to answer a few questions about the past *NV* minutes?") did not differ significantly by environment type, or location. This confirms that we did not have compliance bias by location, or people responding at significantly different rates, depending on environment type.

## RESULTS

Analysis of the data set included two complementary strategies. The first was to produce visualizations that allow designers to understand the temporal and spatial aspects of the data. The second was to perform a classical factor analysis, to determine the significance of qualitatively observed variations, and to assess the ability of the data collection system to produce high quality data sets. It is important to note that this is pilot work to show proof of concept that the tools have value, and to inform the development of questions and visualizations for larger deployments.

### Data Visualization

A data visualization application was developed for the PIR MITes data, which allows users to freely peruse the data for each day, by playing back sensor activations at high speed, or viewing cumulative sensor activation information. The application consists of two main components – a plan view and a timeline. A screen shot of this application is shown in Figure 7.

Upon loading data, the timeline is populated with sensor activations, each represented by a brightened pixel. Every pixel row (across the vertical axis) in the timeline represents a single sensor, and the horizontal axis represents time (from 12:00:00am to 11:59:59pm). The user can then choose to play back the sensor activations, which appear as filled nodes on the plan, or select a time span on the timeline, to view cumulative occupancy and movement, which is parsed from the data. As shown in Figure 7, cumulative occupancy, or time spent in a single location, is

displayed as filled circles, and cumulative movement, or travel between locations, is displayed as thick lines.

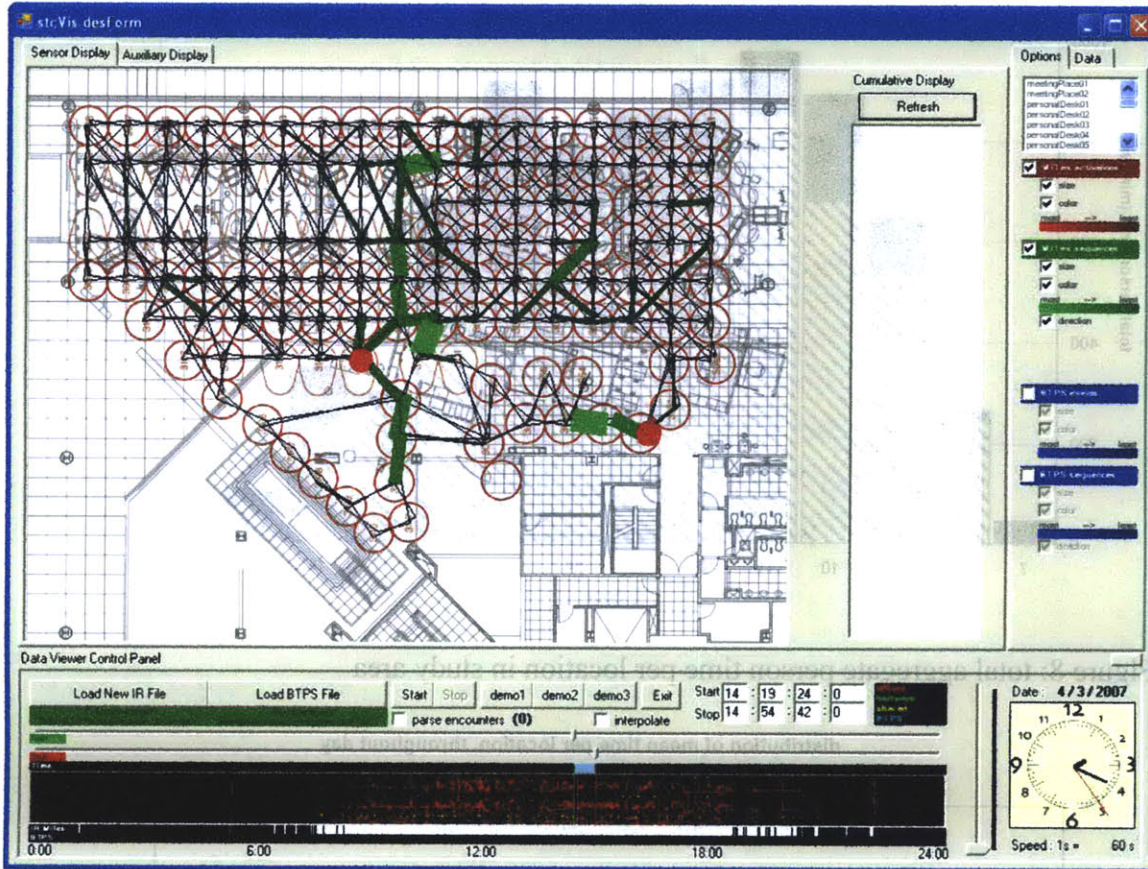


Figure 7: PIR MITes Data Visualization

This application presents the user with an overview of how subjects occupy and move through the space. For design information purposes, this may be most useful for exposing unusual or unexpected behavior, as well as confirming assumptions about how the study environment is used. Including information from the BTPS system, we can also examine the amount of time spent in various locations throughout the space. Figures 8 and 9 show the relative amounts of total and mean time (per activity event), respectively, that subjects spent in the three primary space types<sup>26</sup> throughout the study space, throughout the day.

<sup>26</sup> Significant differences (alpha: 0.10) in behavior (work type and activity quality responses), within these high level environment type categorizations were not found, so locations were clustered, as such.



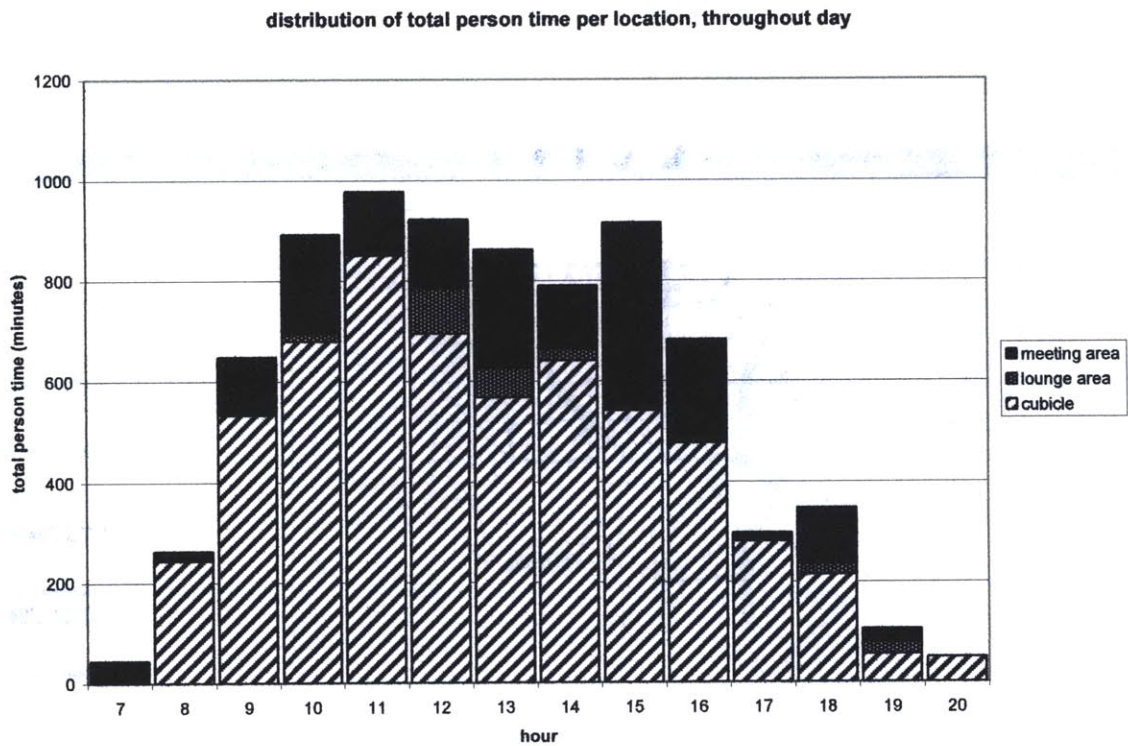


Figure 8: total aggregate person time per location in study area

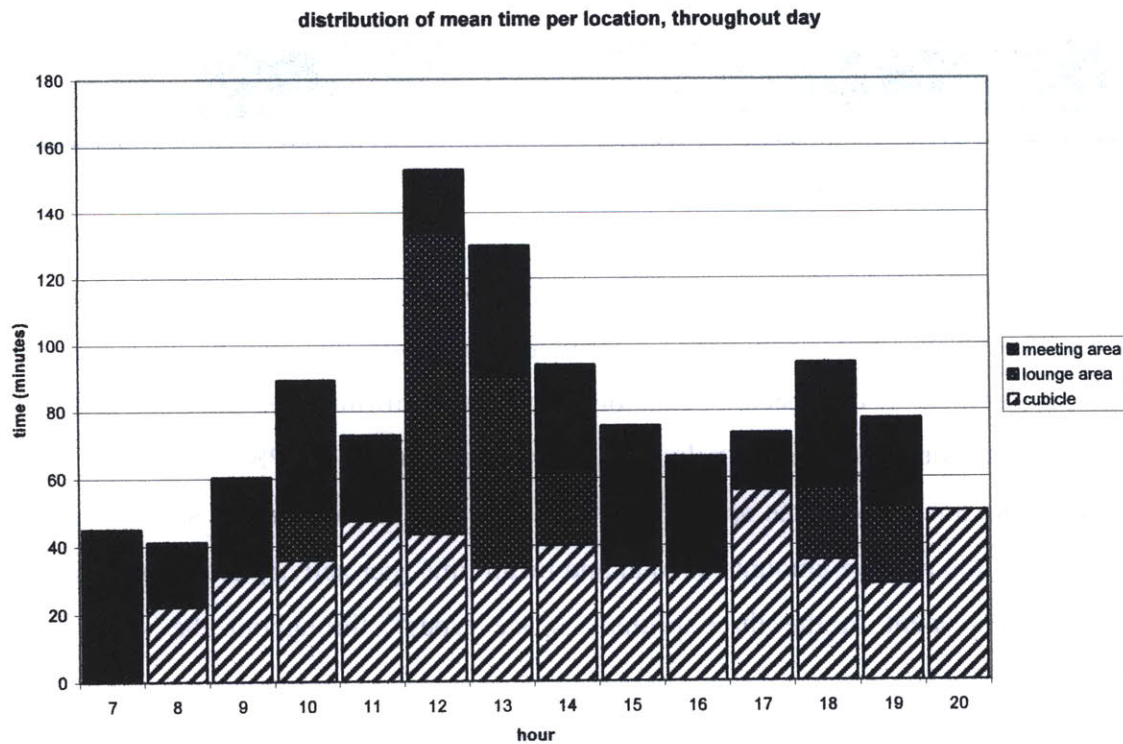


Figure 9: mean person time per location in study area

For space usage mapping, the primary advantage of our automated systems, over traditional methods like ethnographic observation or surveys, is the accuracy and ease of implementation. However, the following figures, showing user responses to questions throughout time, and by environment type or location, might be useful for rapid and accurate assessment of many aspects of behavior that would be difficult to uncover using conventional methods.

As an example, we look at one subject's mean responses to the questions, when asked between 12:00pm and 1:00pm. A graph of these responses, by location, is provided in Figure 10, below. Responses are centered on the horizontal axis, with positive responses to the questions leading up from the axis, and negative responses leading down. The darkness of bars represents normalized significance of the data point – if the subject spent more time in that location, and consistently responded as such, then the bars appear darker.

# a typical late morning for subject10...

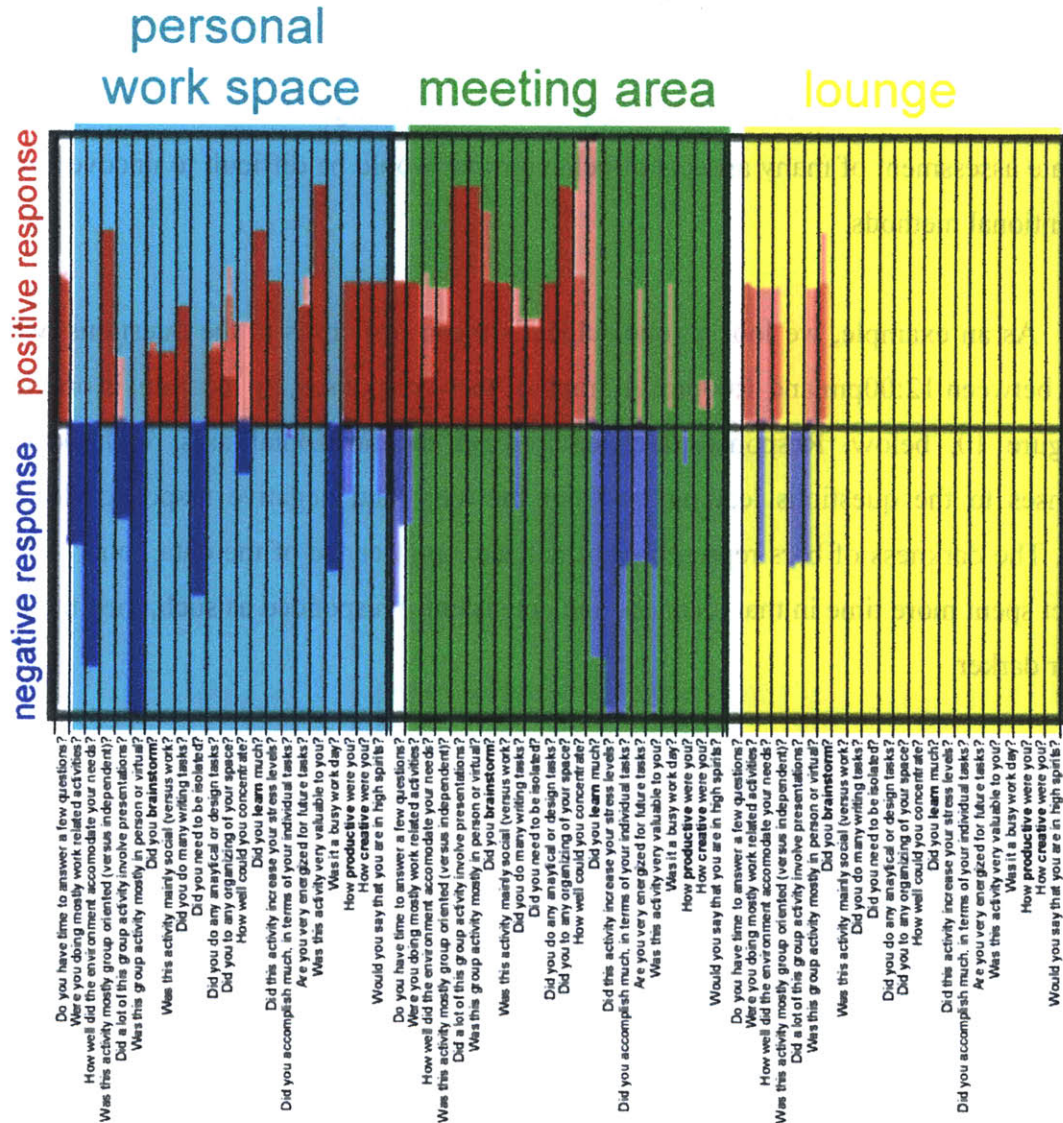


Figure 10: mean perceptions of work quality, subject 10, 12:00pm to 1:00pm

As can be seen in the figure, this subject spent most of his/her time, at this hour, in his/her personal work space or meeting area. When he/she were in his/her personal work space, he/she would generally report not doing work related activities and not really being able to concentrate. This seems perfectly plausible, given the time that is likely to include the subject's lunch break. However, it is interesting to note that the subject



generally reports positive work activity qualities when they are spending this time in a meeting area.

Figure 11 shows an array of these graphs, for all subjects, for all hours of the day for which data was collected. This type of representation allows the researcher to quickly scan the large amount of data for unusual features that deserve further exploration. This is intended to take advantage of the human ability to discern visual patterns – and in particular, the ability to rapidly identify breaks in patterns. Examples of such features are shown in Figure 12.<sup>27</sup>

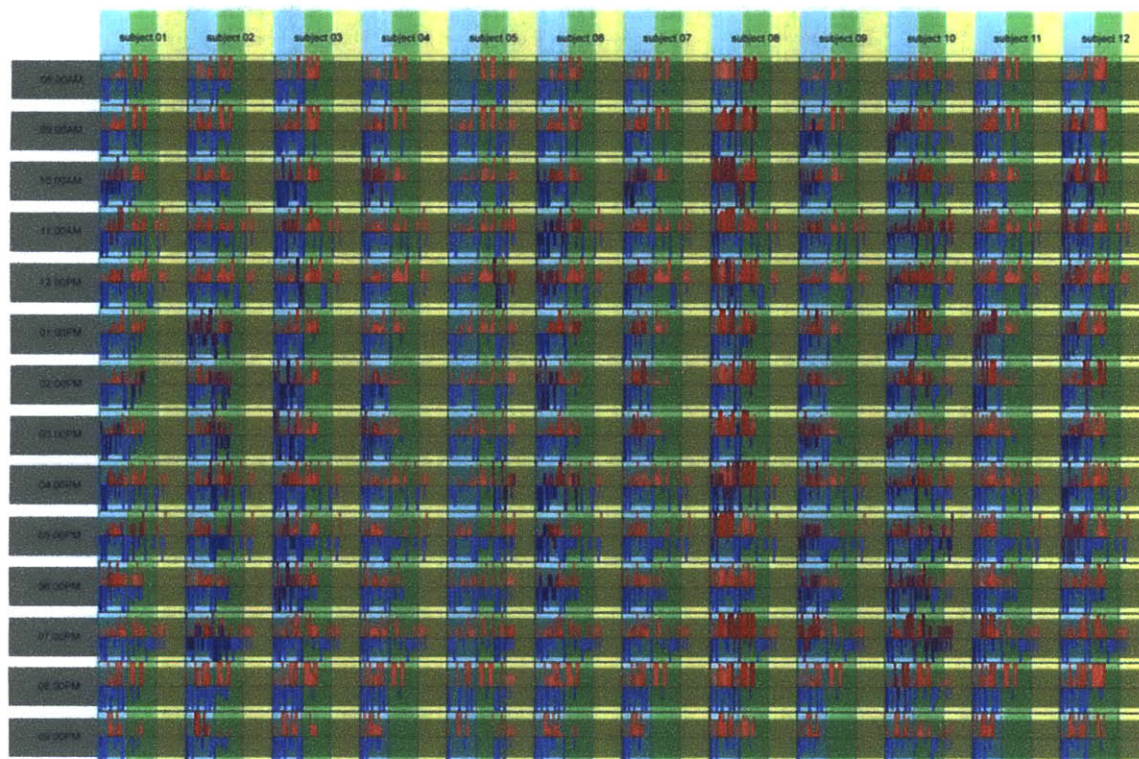
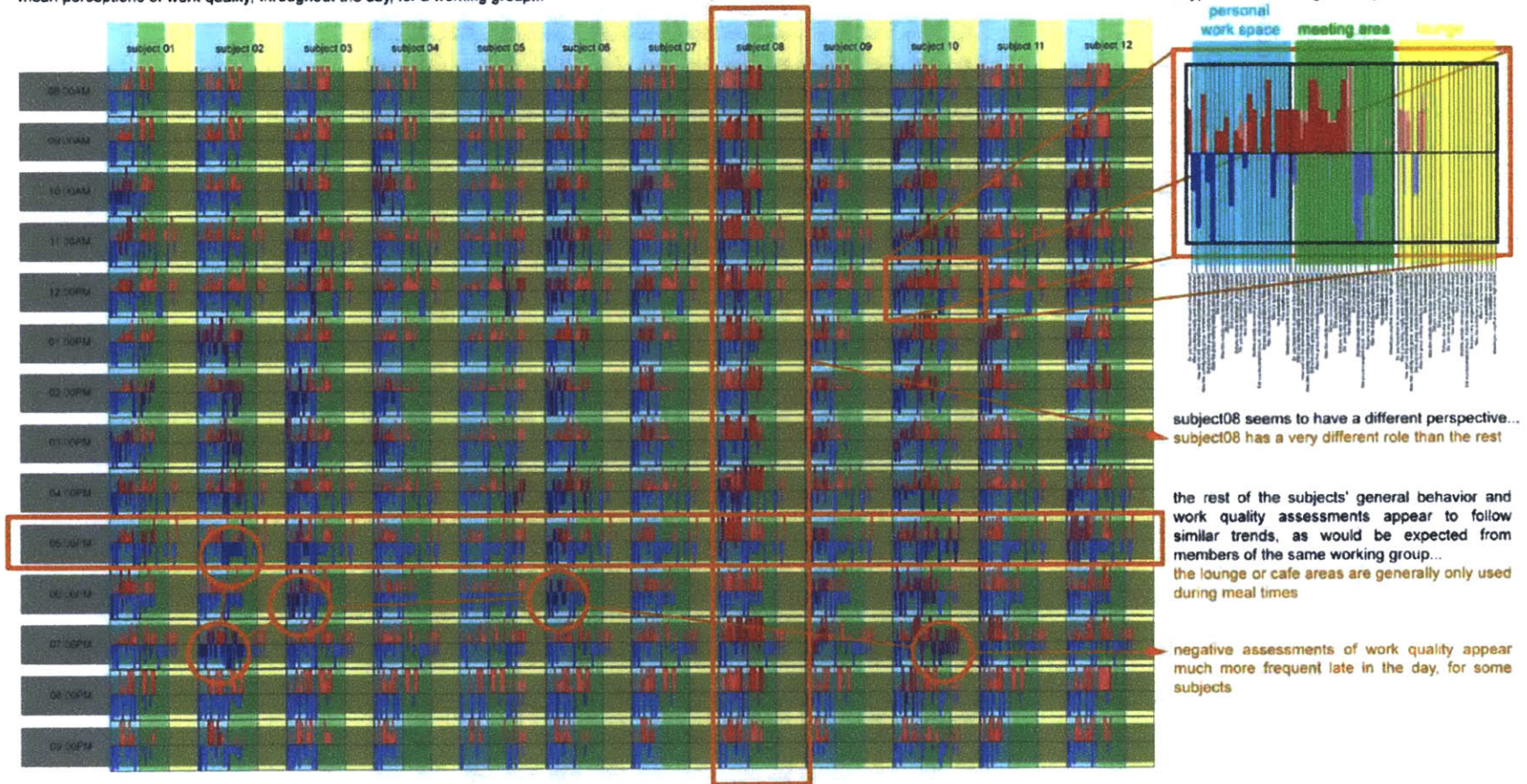


Figure 11: mean perceptions of work quality, per subject, per hour

<sup>27</sup> (next page) Figure 12: mean perceptions of work quality, per subject, per hour



mean perceptions of work quality, throughout the day, for a working group...





The most immediately apparent feature is that subject 08 seems to have a notably different perspective than the rest of the subjects. Review of this result with the study group revealed that this subject has a slightly different role than the rest of this working group. The rest of the subjects' general behavior and work quality assessments appear to follow similar trends, as would be expected from members of the same working group. For instance, the lounge areas are generally only used during meal times, if at all, by any subject. Further, negative assessments of work quality appear more frequently later in the day, for a portion of the subjects.

The data visualization can be transformed in a variety of ways, each providing a new perspective on the behavior that occurred in the office. To look closer at behavior at specific locations, all subjects' mean responses to a single question, for a single location, over the entire study period, can be plotted. A graph of these responses, by subject, is provided in Figure 13, below, for the question – “Were you involved in group (versus independent) activity?” Responses are again centered on the horizontal axis, as in the previous example. The darkness of bars also represents normalized significance of the data point.

group (versus independent) activity...

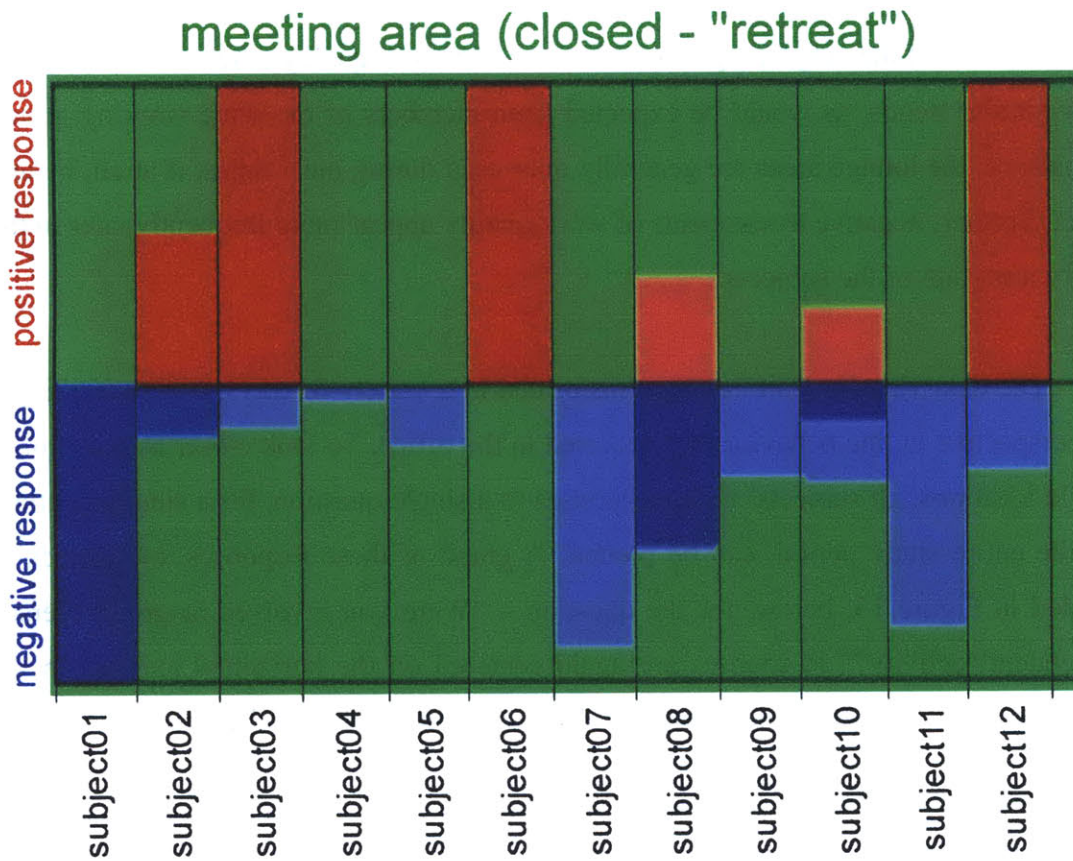


Figure 13: mean assessment of work type, for the closed meeting area

As can be seen in the figure, different individuals consistently utilize this space in different ways. Subject 01 and subject 08 are more likely to use the closed meeting area for independent activity, while most subjects are most likely to use the space for group activity. The remaining few use the space less often, or vary their use between independent and group activities. This is certainly informative for designers – to know, for instance, that the closed meeting space is utilized in varying ways by different individuals. Figure 14 shows an array of these graphs, for all locations, for all work activity quality questions.

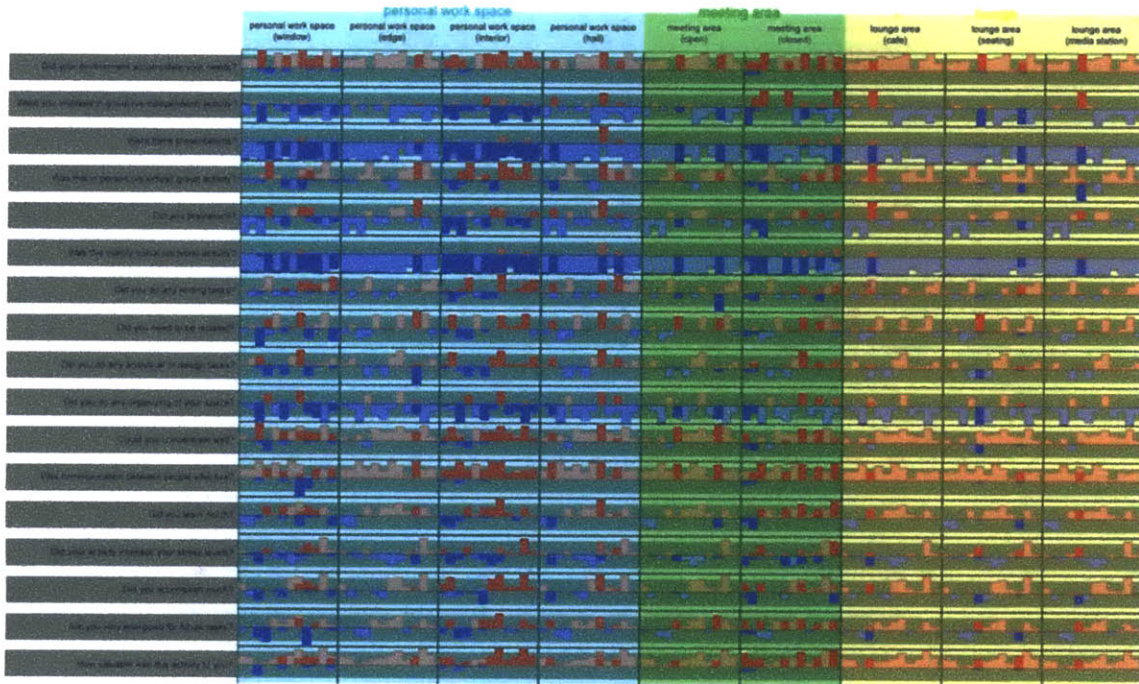


Figure 14: mean perceptions of work quality, per subject, per hour

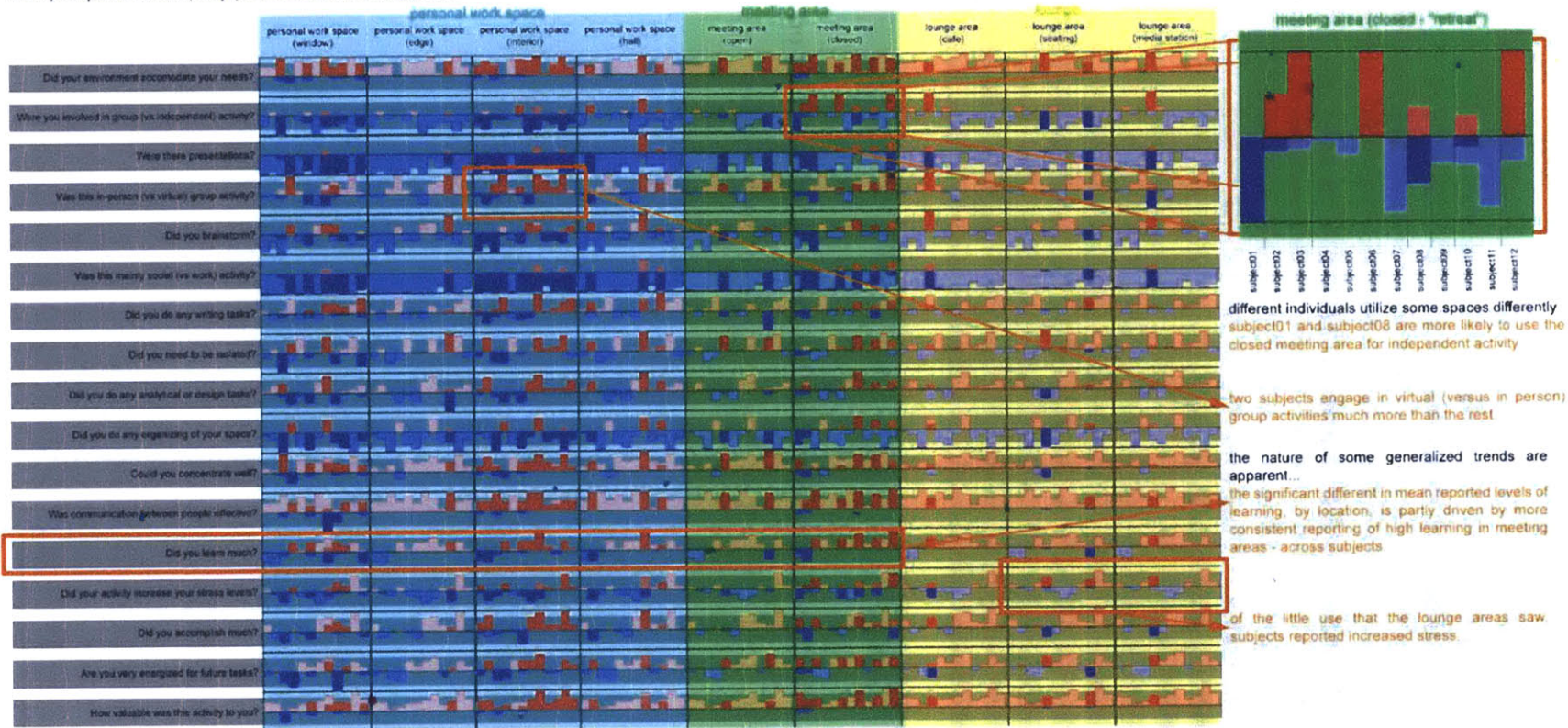
Again, this type of representation allows the researcher to pick out visual features in a large dataset, for further exploration. Examples of such features are shown in Figure 15.<sup>28</sup>

<sup>28</sup> (next page) Figure 15: mean perceptions of work quality, per location, per subject



mean perceptions of work quality, per location, for a working group...

group (versus independent) activity...



Individual features are apparent throughout – for instance, two subjects appear to engage in virtual group activities more than the rest, and of the little use that lounge areas saw, subjects tended to report increased stress. The natures of possibly general trends are also apparent. Most interestingly, one can see differences in variance between subjects, across locations, that show that certain spaces provide subjects with a more universally suitable (or unsuitable) environment for certain activities or behavior.

To further examine this notion, we proceeded with a classical factor analysis of the data set.

### Factor Analysis

In this section, the focus of our analytic strategy was to assess the interactions between environment type and work type and workplace activity quality.<sup>29</sup> We performed an analysis of variance (ANOVA) for responses to each question, by environment type. Responses to the following workplace activity quality scales were found to differ significantly by environment type ( $P < 0.10$ ):

Q01: "How much of your time, for the past NN minutes, were you doing work related activities ('None' → 'All')?"

Q04: "Did you feel that, during this time, your environment accommodated your needs ('no' → 'yes')?"

Q05: "How much of this time involved independent activity, versus group activity ('independent' → 'group')?"

Q06: "How much of this group activity involved presentations ('none' → 'all')?"

Q14: "How well could you concentrate during this time ('not well at all' → 'very well')?"

Q15: "During this time, how effective was communication between people ('not effective' → 'very effective')?"

Q16: "Did you learn much ('no' → 'yes')?"

Q17: "How did your activity, during this time, affect your stress levels ('decreased stress' → 'increased stress')?"

Q19: "Are you more or less energized for future tasks ('not energized' → 'very energized')?"

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<sup>29</sup> Please see Appendix H for the factor analysis results; question responses as dependents, location as factor

As expected, subjects' assessments of whether their activities were work related were found to differ significantly by location. Not surprisingly, subjects reported activities in the lounge areas as being less work related. This is a case where the tools happened to provide data on a dimension for which we have strong expectations. Seeing that the results from the tools match these expectations suggests that the data collected is valid.

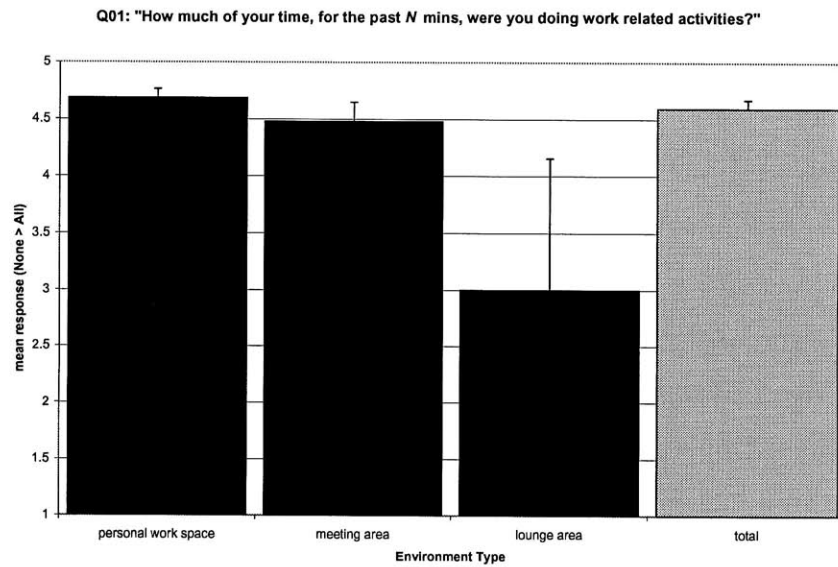


Figure 16: Q01 ( $P < 0.05$ )

Subjects' assessments of whether their environment accommodated their needs were also found to differ significantly by location. Notably, subjects reported meeting areas as being the most accommodating.

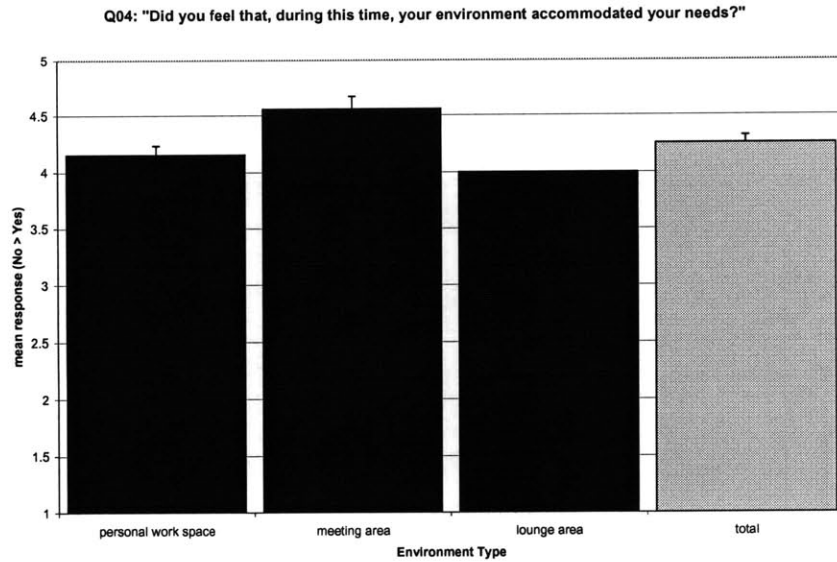


Figure 17: Q04 (P<0.05)

As expected, subjects' assessments of whether their activities were independent or group oriented were also found to differ significantly by location. Not surprisingly, subjects reported most group oriented activities in the meeting areas; interestingly, subjects reported most independent activities in the lounge area.

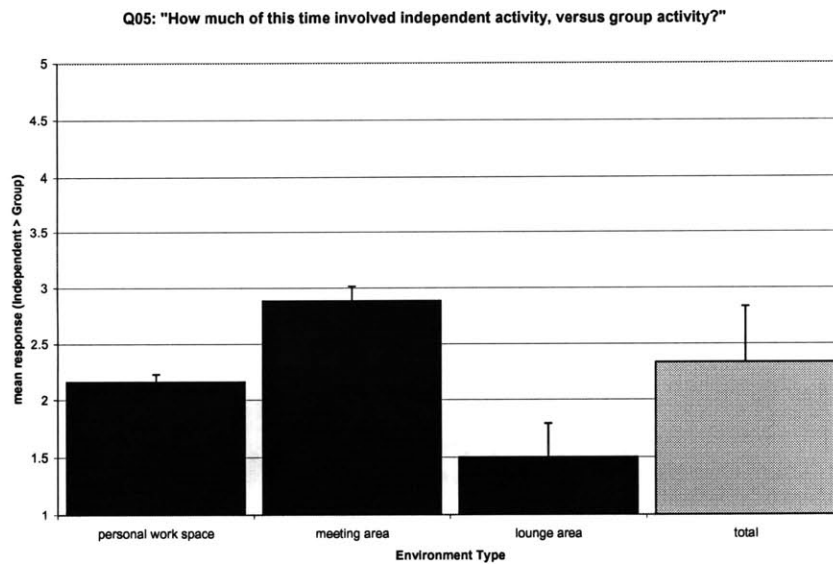


Figure 18: Q05 (P<0.05)

Subjects' assessments of whether their activities involved presentations were also found to differ significantly by location. Not surprisingly, subjects reported most presentations in the meeting areas (and none in the lounge areas).

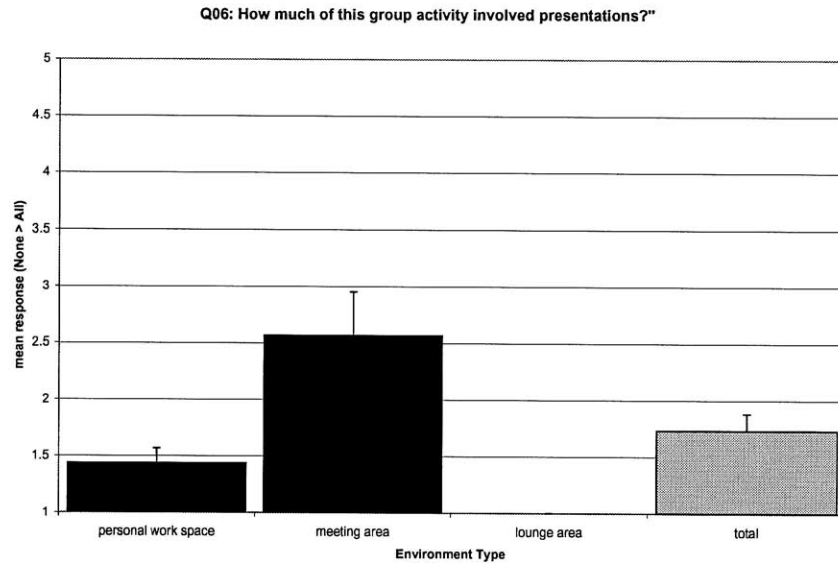


Figure 19: Q06 ( $P < 0.005$ )

Subjects' assessments of their ability to concentrate were also found to differ significantly by location. Interestingly, subjects reported the best ability to concentrate in the meeting areas, and least ability to concentrate in the lounge areas.

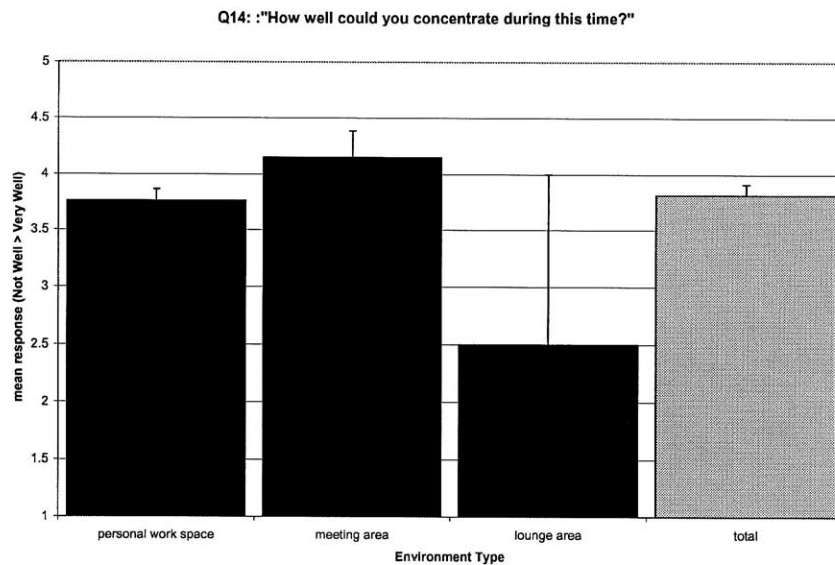


Figure 20: Q14 ( $P < 0.10$ )



Subjects' assessments of the effectiveness of communication were also found to differ significantly by location. Subjects reported the most effective communication in the meeting areas, and least effective communication in the personal work spaces.

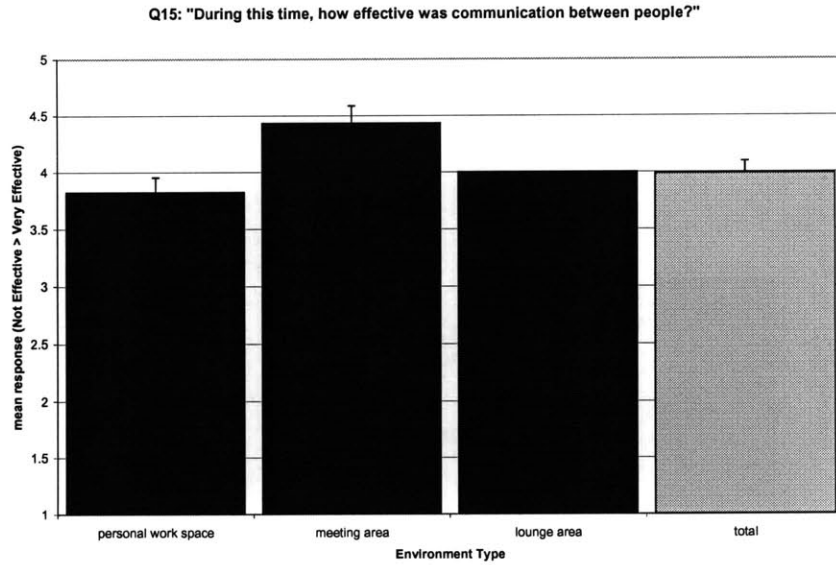


Figure 21: Q15 (P<0.05)

Subjects' assessments of whether or not they learned were also found to differ significantly by location. Interestingly, subjects reported the most learning in the meeting areas, and least learning in the lounge areas.

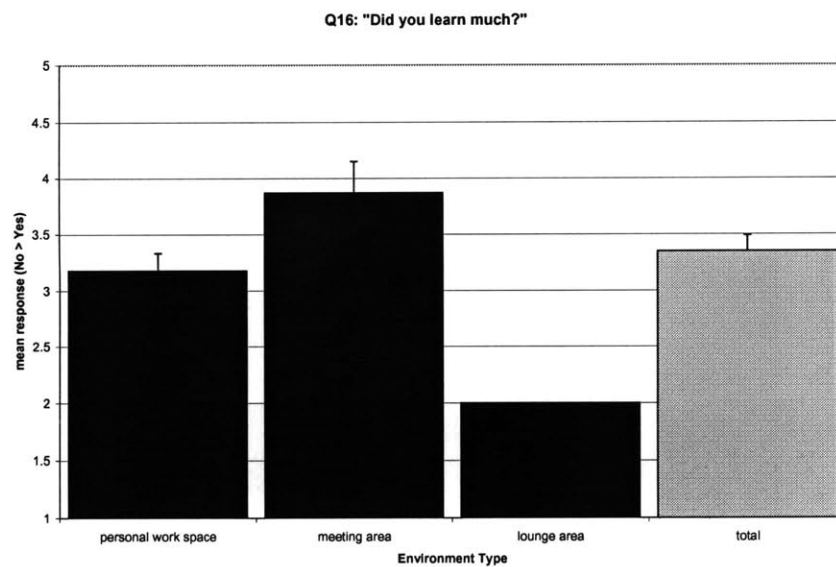


Figure 22: Q16 (P=0.05)

Subjects' assessments of activities' effects on their stress levels were also found to differ significantly by location. Interestingly, subjects reported the most increase in stress in the lounge areas.

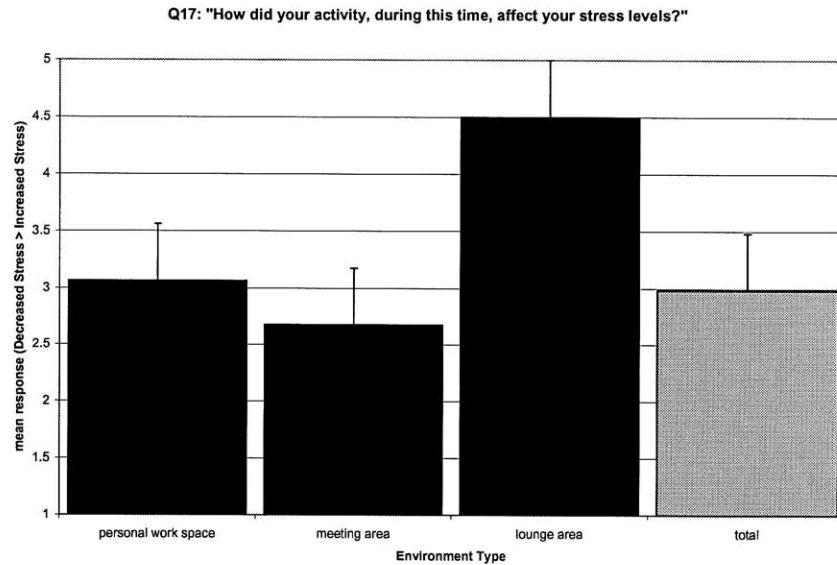


Figure 23: Q17 ( $P < 0.10$ )

Subjects' assessments of whether or not they are energized for future tasks were also found to differ significantly by location. Interestingly, subjects reported that they were least energized following activities in the lounge areas.

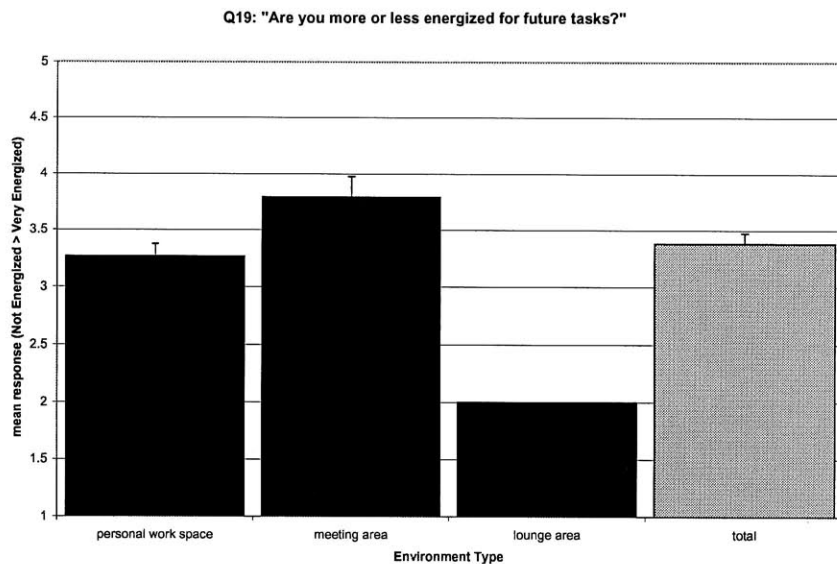


Figure 24: Q19 ( $P < 0.05$ )

As this is a small pilot study, the primary point of this analysis was to show the feasibility of this type of data collection. This type of system can be used to determine probing questions to follow up on and possibly help a designer gather desired information more quickly and cost-effectively.

## DISCUSSION

This study makes a main contribution of demonstrating how the technologies of mobile devices and sensor networks might be used to study and evaluate the behavior of people in architectural environments. The ease and accuracy – as is made possible by our systems – with which such behavioral information can be collected lends itself greatly to use by responsible designers who wish to understand the relationship between design and behavior. Further, the data that can be collected with our systems can be structured through visualizations in a way that provides designers with the ability to discern important features in the data, from a very large space of possible features, by focusing on the meanings of visual features in a graph. The type of data collection and visualization proposed here might help a designer to quickly determine a subset of informative questions to ask a set of users. The overview data may allow designers to pick out important behavioral phenomena that would be difficult to obtain with other methods of occupancy analysis.

The findings also suggest that in the case of the twelve Steelcase subjects, environment type, as categorized by design intention, can indeed be a predictor for activity types as well as numerous qualitative dimensions, as is often assumed by design professionals. What this work does not tell us is explicitly how or why this can occur, but as pilot work, it may justify future studies using the tools to investigate the specific mechanisms through which such behavior responses occur.

With a long term goal of implementing studies that control for various associations with environments such as would be necessary to determine if specific

physical environmental variable contributions to the observed differences, we discuss the implications of these results with respect to research methods and enabled design methods.

The experience sampling system, coupled with the bluetooth positioning system, demonstrates a new method for evaluating environments. This system can be further coupled with PIR MITes data, to increase the space of activities that can be automatically recognized (and responded to, for instance, with queries). Based on our experiences with these systems, the Bluetooth Positioning System is sufficient for recognition of activities that only require information regarding basic room level positioning. However, addition of other types of MITes data<sup>30</sup> would enable a similar system to recognize activities based on parameters such as use of devices or furniture, physical environmental conditions such as temperature, or even activity of each user (such as whether or not the user is sitting, standing, or walking).

Visualization of the data still deserves much future work. Initial experiments with projecting real time and played back data on floor plan underlays were found to be difficult to interpret, and most importantly did little to expose features in the data that were not already understood. Early experiments with computational information design also suffered from the constraint that the results tended to show a few possible feature parameters quite well, but entirely suppressed other possible interactions. For example, a valence display that shows circles as locations, with pathways between locations expressed as lines, was built to monitor the MITes system. Relative size and distance of each circle – from the center of the figure – is determined by the relative frequency of MITes activations in each space, allowing the viewer to rapidly pick out which spaces contain the most activity, along with the relative use of spatial connectivity. It is expected that continued work with computational information design will yield even more useful visualizations that enable researchers to quickly peruse the data for many different types of features.

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<sup>30</sup> Other MITes types developed by the MIT House\_n Research Consortium include and are not limited to On-Body Accelerometers, Object Motion Accelerometers, Electrical Current Sensors, Fluid Flow Sensors, Light Sensors, Temperature Sensors, Humidity Sensors, and Heart Rate Sensors.

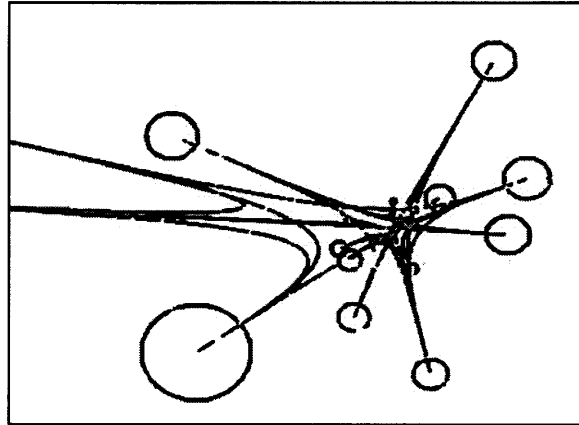


Figure 25: screenshot of experimental real time valence<sup>31</sup> display of space usage

To interpret the analytical results of this study, it is important to note the notion that a person may self select into environment type, by activity, and that this partially accounts for the reported effects. In other words, perhaps it is the case that environment type has certain effects due to its physical characteristics combined with users' prior learned associations with other characteristics, such the name of a space. These other characteristics may strongly influence the choice of environment type for certain activities. Social support may play a role in this possible mechanism, also. Perhaps physical characteristics of these areas draw people together or spread them sparsely throughout the space, providing varying context for in person interactions.

As such, the principal focus of future studies could be on the buffering or interactive effects, not the main effects of specific environmental factors. Therefore, any alternative explanation for results, including selection bias, has to account for the interactions on the outcomes. The argument that learned associations with environmental types or some other construct is a viable alternative explanation is much more difficult to make for interaction outcomes. Alternatively, an extremely well controlled experiment involving the changing of space layouts over long periods of time (to allow for adjustment) would provide the best information.

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<sup>31</sup> After Ben Fry's Valence displays of text, genome data (2004)

A large study with a large population, in a larger space, over a longer period of time, where the characteristic work types that occur across environment types is more variable, is now called for. It would also be effective to include measurements of environment type as continuous variables. The measurement of environment type as a set of continuous variables, rather than as a nominal variable, would allow researchers to more confidently rule out possible confounding variables, which might be collinear with definitions of environment type in a circumstance where environment type is measured nominally. For example, in some situations the absence or presence of a café area is likely to co-vary with other factors, such as the overall quality of the environment.

## FUTURE WORK

This pilot work has shown that sensor technology may provide useful information for designers that would otherwise be time consuming (and therefore costly) to obtain. A clear next step is to use this system in a complete experiment involving pre-design data collection, design and build, and post occupancy data collection, to address questions of how well the system can enable designers' ability to predict user behavior. In addition to further exploration of the mechanisms underlying environment type as a predictor for activity quality, further research ought to explore the generalizability of the present findings. Future work might explore whether environment type is similarly predictive in different types settings (home, school) and with other populations and ages.

Beyond understanding existing patterns of inhabitation, to better understand the design problem, these systems have three other significant potential uses. An application that is already under development is for evaluating finished works, in terms of stated goals of design, in terms of occupant behavior. Another is for evaluating prospective designs, using computational models of inhabitation, in a virtual design environment, and a final speculative application is for generative design tools based on computational models of inhabitation.

## Evaluating Finished Works

Steelcase, Inc., is a multi-billion dollar (USD) multi-national corporation that provides business solutions through the creation of well designed working environments. The Community Based Planning (CBP) toolkit, developed by Steelcase, is used by Steelcase's consulting services to analyze workspaces and then make recommendations about how those spaces could be redesigned. The CBP toolkit is a guide that can be used to ultimately specify different types of environments, based on the organizational and business goals of the client. These goals are initially described in terms of four categories – Work Process, Innovation, Communication, and Learning. The end result of the consulting process includes selection and placement of any of forty one types of environments that have been enumerated as a set of prototypical environments that functional workplaces are composed of. Each of these environments is defined in terms of eighty four dimensions of the behavior and activities of users of the environment.<sup>32</sup>

Of the eighty four dimensions of the behavior and activities of users of the CBP prototypical environments, sixteen are clearly well suited for use of the quantitative sensing tools that we have developed. Seven of these dimensions cover the duration and frequency of use of each environment, and are best resolved with our passive infrared MIT environmental sensors (PIR MITes).<sup>33</sup> The other nine dimensions cover the number and frequency of use by number of occupants, and are best resolved with our mobile positioning system (BTPS).<sup>34</sup> Using just these sixteen dimensions, thirty two of the forty one prototypical environments can be partitioned.<sup>35</sup> This kind of information – quantitative occupancy size and frequency – is clearly significant to defining the kinds of environments that are necessary, as defined by the CBP toolkit.

The remaining sixty eight dimensions of behavior and activities of users of the CBP prototypical environments can be described as qualitative dimensions. These

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<sup>32</sup> Please see Appendix B for a table of these behaviors and activities.

<sup>33</sup> [http://architecture.mit.edu/house\\_n/MITes/](http://architecture.mit.edu/house_n/MITes/)

<sup>34</sup> Cheung, Intille, & Larson, 2006

<sup>35</sup> Please see Appendix C for a table of dimensions partitioned by our systems.

dimensions can be attained through experience sampling. Because of time constraints, for the purpose of this project, we needed to condense these dimensions to a small set that could be incorporated into a tolerable experience sampling application. A group (n=6) of subjects were asked to help distill these dimensions in two phases. The first phase involved grouping the dimensions, by name, into broad categories. The significant categories that resulted were Group Activity Goals (fifteen dimensions), Presentation Goals (nine dimensions), and Independent Goals (sixteen dimensions). The remaining few dimensions were not grouped similarly by the subjects. The second phase of categorization involved grouping the dimensions within each category by task. The resulting tasks were Brainstorming, Collaborating, and Socializing (Group Activity Goals); Analyzing, Executing, and Organizing (Independent Goals); and Broadcasting and Inspiring (Presentation Goals). These eight dimensions were then applied back to the table of sixty eight qualitative dimensions, and normalized to determine their relationship to the prototypical environments, using the quantity and values of the primitive dimensions that were categorized into these final eight.

Using these eight dimensions, along with three concerning privacy of space (private, semi-private/public, public), thirty six of the forty one prototypical environments can be partitioned. Combined with the aforementioned quantitative dimensions, forty of the forty one prototypical dimensions can be effectively partitioned.<sup>36</sup> This gives us a basis for an automated system that evaluates a set of dimensions that encompasses those in CBP.

The goals of this future project include supplementing existing design tools with the information collected with automated sensor systems, as well as providing feedback for the further development of design tools such as CBP.

In terms of addressing CBP, we are interested in the manner by which environments are defined as needing to support certain behaviors and activities. If we

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<sup>36</sup> The two prototypical environments defined in the CBP toolkit that are indistinguishable using these dimensions are the “Cyber Café” and the “Media Café.”



consider the sixteen quantitative dimensions and only the eleven condensed qualitative dimensions from our analysis of the CBP toolkit, considering certain categories to be inclusive or exclusive, and negating appropriate cases that involve lack of data, we have a space of  $6.7473 \times 10^6$  possible prototypical spaces that could be defined by this system. So, we would like to look at the assumption that the forty one environments defined by CBP partition this space in a meaningful way, and that most of the locations throughout the state space are trivially different from the forty one prototype spaces.

We can use our systems to collect data in two regimes: how the space functions, and what kinds of spaces (as defined by function) the users want. For the first (how the space functions), this can be presented to designers as both an informational set of data, and an introspective look at the CBP toolkit. The informational aspect can be presented as a map of significant locations, along with the data about how they are used in terms of the twenty eight dimensions. The introspective aspect will include a determination of which of the forty one prototypical spaces are most closely matched to the existing spaces. It is expected that this may result in affirmations of the prototypical spaces (i.e. “this existing space would clearly be made much better with the changes that would be entailed in transforming it to [a particular prototype environment]”) or perhaps some editing of CBP (i.e. “this existing space performs a function is valuable, but is not included in CBP; therefore, we may add it to CBP,” or “this existing space fits the definitions of a prototypical environment defined in CBP, but isn’t arranged how we envisioned it; therefore, we may expand its definition in CBP”).

### Evaluating Prospective Designs

There is ongoing research on computational architectural critique tools, whereby the computer system is designed to recognize designs that fit a particular style or set of building codes, and provides feedback to a designer through a virtual CAD environment. With behavioral models obtained with our systems, these may include the ability to deploy virtual inhabitants who can then virtually report back to the designer as to whether or not their desired behavior is accommodated by a design.

## Generative Design Tools

Computational models of user behavior, developed using ubiquitous computing systems, may be used in generative design tools. For instance, these computational models may be used to predefine statistical information about spatial relationships between spaces, to guide rule sets for cellular automata or growth simulations.<sup>37</sup>

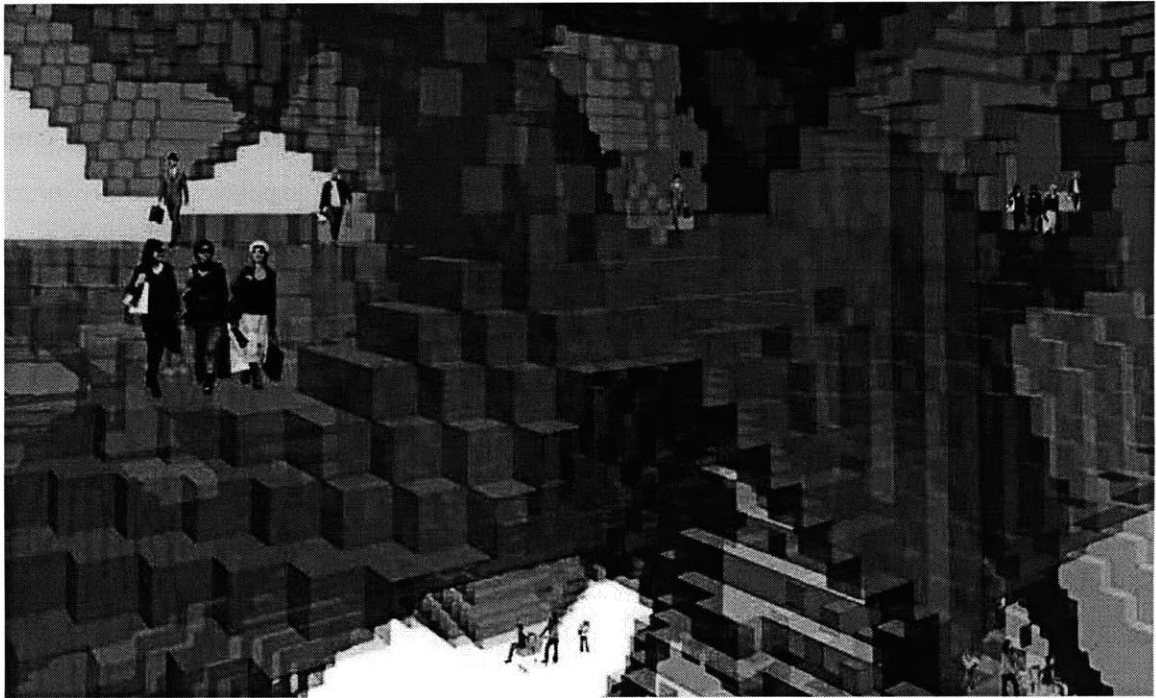


Figure 26: computational generative design

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<sup>37</sup> Cheung, 2005

## Appendix A – Occupancy Evaluation Systems

Dutch Building Decree (Scholten 2001)  
Value frames (Rutten and Trum 1998)  
ORBIT (Vijverberg 1999)  
Organisational Workplace Analysis (Baird et al. 1996)  
Serviceability Tools and Methods (Vijverberg 1999)  
ISO ([www.iso.ch](http://www.iso.ch)) International Organization for Standardization  
ASHRAE ([www.ashrae.org](http://www.ashrae.org))  
CIB ([www.cibworld.nl](http://www.cibworld.nl))  
International Council for Research and Innovation in Building and Construction Building in Use Studies (Baird et al. 1996)  
PeBBu 2004 Performance Based Building  
JVAK-analysis (Hiffineijer 1997)  
Flexis (Geraerds 1998)  
CEN ([www.cenorm.be](http://www.cenorm.be)) European Committee for Standardization  
FiSL4Q Finnish Society of Indoor Air Quality and Climate  
Dutch Energy Performance Standard (NEV 1998)  
TWLV (Haas 1998)  
Eco-Quantum (Boonstra and Knapen 1998)  
Environmental index (Dew ever 2000)  
Envest (Luke 2000)  
Building-in-use method (Tischer 1989,)  
BOSTI (Wagenberg and Wilmes 1989)  
Physical Building Audit (Baird et. al. 1996)  
Building Quality Assessment (Baird et al. 1996)  
Real Estate iVorm (REN 1992)  
Post occupancy Review Of Buildings and their Engineering PROBE (Cohen et al. 1997)  
TOBUS (Caccavelli et al. 2000)  
BREEAM (Baldwin et al. 1998)  
Test Healthy Office (SBR 1998)  
Building Symptom Index (Bluyssen et al. 1995)  
Whole Building Functionality and Serviceability (ASTM 2000)  
LEED Green Building Rating System ([http: www.usbc.org/LEED](http://www.usbc.org/LEED))

Appendix B: CPB dimensions of behavior and activities

|               |                                 |
|---------------|---------------------------------|
| Serves        | Organization                    |
|               | Group                           |
|               | Individual                      |
| Access        | Public                          |
|               | Semi-private                    |
|               | Private                         |
|               | Confidential                    |
| Ownership     | Owned                           |
|               | Shared                          |
|               | Assigned                        |
| Use           | Individual                      |
|               | Group                           |
| Duration      | Minutes                         |
|               | Hours                           |
|               | Days                            |
|               | Months                          |
| Frequency     | Daily                           |
|               | Weekly                          |
|               | Monthly                         |
| Size          | Scalable                        |
|               | Always small                    |
|               | Always medium                   |
|               | Always large                    |
| Steps         |                                 |
| Work Process  | Understand tasks                |
|               | Combine information in new ways |
|               | Execute a procedure             |
|               | Deliver, share, and store       |
| Innovation    | Understand the problem          |
|               | Create new ideas                |
|               | Realize solutions               |
| Communication | Prepare, organize, and format   |
|               | Broadcast to audience           |
|               | Receive                         |
|               | Feedback to confirm understood  |
| Learning      | Input, collect data             |
|               | Analyze, give meaning           |
|               | Synthesize, distill, share      |
| Problems      |                                 |
| Work Process  | Process explicit                |
|               | User control                    |
|               | Resource management             |
|               | Collaborate, concentrate, flow  |

|               |                                       |
|---------------|---------------------------------------|
|               | Multi-tasking                         |
|               | Diverse collaboration                 |
|               | Accommodate visitors                  |
| Innovation    | Stimulate and inspire                 |
|               | Accelerate idea generation            |
|               | Diverse needs                         |
|               | Accommodate rapid change              |
|               | Learning from past                    |
| Communication | Informal interaction                  |
|               | Connect isolated groups               |
|               | Express group identity                |
|               | Display information                   |
|               | Security                              |
| Learning      | Motivation                            |
|               | Inter-group learning                  |
|               | Diverse learning styles               |
|               | Mentoring                             |
|               | Organization's vision                 |
|               |                                       |
|               | Welcome, orient                       |
|               | Touch-down (work on the go)           |
|               | Wayfinding, navigate                  |
|               | Meet, encounter                       |
|               | Relax, rest                           |
|               | Reason, reflect, deep think           |
|               | Play                                  |
|               | Socialize                             |
|               | Eat, drink                            |
|               | Kinko-ing (resource sharing)          |
|               | Store, retrieve                       |
|               | Train                                 |
|               | Gather information                    |
|               | Organize, analyze, and understand     |
|               | Generate ideas, brainstorm            |
|               | Synthesize                            |
|               | Learn-by-doing                        |
|               | Turn ideas into reality, prototype    |
|               | Concentrated work, hunker down        |
|               | Post, display information             |
|               | Present information (live)            |
|               | Information immersion, feed your head |
|               | Transfer knowledge                    |
|               | Exchange feedback                     |
|               | Swap ideas                            |

Appendix C: CBP dimension partitioning with automated systems

| Qualitative Partitioning | Serves             |              |                | Use              |             | Duration |       |      |        | Frequency |        |         | Size     |                    |                     |                   |
|--------------------------|--------------------|--------------|----------------|------------------|-------------|----------|-------|------|--------|-----------|--------|---------|----------|--------------------|---------------------|-------------------|
|                          | Organization (12+) | Group (2-11) | Individual (1) | Individual (T/F) | Group (T/F) | Minutes  | Hours | Days | Months | Daily     | Weekly | Monthly | Scalable | Always small (1-2) | Always medium (3-5) | Always large (6+) |
| Kickstart Café           | 1                  |              |                | 1                | 1           | 1        | 1     |      |        | 1         | 1      |         | 1        |                    |                     |                   |
| Cyber Café               | 1                  |              |                | 1                | 1           | 1        | 1     |      |        | 1         |        |         | 1        |                    |                     |                   |
| Media Café               | 1                  |              |                | 1                | 1           | 1        | 1     |      |        | 1         |        |         | 1        |                    |                     |                   |
| Cyber Amphitheater       | 1                  |              |                | 1                | 1           | 1        | 1     |      |        |           | 1      |         |          |                    |                     | 1                 |
| Welcome Center           | 1                  |              |                | 1                | 1           | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Idea Concourse           | 1                  |              |                | 1                | 1           | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Rendezvous               | 1                  |              |                | 1                | 1           | 1        |       |      |        | 1         |        |         |          | 1                  |                     |                   |
| Library Café             | 1                  |              |                | 1                | 1           |          | 1     |      |        |           | 1      |         | 1        |                    |                     |                   |
| Arena Back Stage         | 1                  |              |                | 1                | 1           |          |       |      | 1      | 1         |        |         | 1        |                    |                     |                   |
| Service Center           | 1                  |              |                | 1                |             | 1        | 1     |      |        |           | 1      |         |          |                    |                     | 1                 |
| Getaway                  | 1                  |              |                | 1                |             | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Main Street              | 1                  |              |                | 1                |             | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Resource Station         | 1                  |              |                | 1                |             | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Display Way              | 1                  |              |                | 1                |             | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Info Center              | 1                  |              |                | 1                |             | 1        |       |      |        | 1         |        |         |          |                    | 1                   |                   |
| Way Station              | 1                  |              |                | 1                |             |          | 1     | 1    |        | 1         |        |         |          |                    | 1                   |                   |
| Cyber Forum              | 1                  |              |                |                  | 1           |          | 1     | 1    |        | 1         |        |         |          |                    |                     | 1                 |
| Training Center          | 1                  |              |                |                  | 1           |          | 1     |      |        | 1         |        |         |          |                    |                     | 1                 |
| Smart Room               | 1                  |              |                |                  | 1           |          | 1     |      |        |           | 1      |         |          |                    | 1                   |                   |
| Lab Central              | 1                  |              |                |                  | 1           |          |       | 1    |        | 1         |        |         | 1        |                    |                     |                   |
| Arena Road Show          | 1                  |              |                |                  | 1           |          |       |      | 1      | 1         |        |         | 1        |                    |                     |                   |
| Inner Circle             | 1                  |              |                |                  | 1           |          |       |      | 1      | 1         |        |         | 1        |                    |                     |                   |
| Club Café                |                    | 1            |                | 1                | 1           | 1        | 1     |      |        | 1         |        |         | 1        |                    |                     |                   |
| Community Courtyard      |                    | 1            |                | 1                | 1           | 1        |       |      |        | 1         |        |         | 1        |                    |                     |                   |
| Oasis                    |                    | 1            |                | 1                | 1           |          | 1     |      |        | 1         |        |         | 1        |                    |                     |                   |
| Retreat                  |                    | 1            |                | 1                |             | 1        | 1     |      |        | 1         |        |         |          | 1                  |                     |                   |
| Trading Post             |                    | 1            |                | 1                |             | 1        |       |      |        |           | 1      |         | 1        |                    |                     |                   |
| Meet'n Go                |                    | 1            |                | 1                |             | 1        |       |      |        |           | 1      |         |          |                    | 1                   |                   |
| Learning Lab             |                    | 1            |                | 1                |             |          | 1     |      |        | 1         |        |         | 1        |                    |                     |                   |
| Idea Alley               |                    | 1            |                | 1                |             |          | 1     |      |        |           | 1      |         | 1        |                    |                     |                   |
| Mentor Pod               |                    | 1            |                | 1                |             |          | 1     |      |        |           | 1      |         |          | 1                  |                     |                   |
| Arena Front Stage        |                    | 1            |                |                  | 1           |          | 1     |      |        | 1         |        |         | 1        |                    |                     |                   |
| Home Port                |                    | 1            |                |                  | 1           |          | 1     |      |        |           | 1      |         | 1        |                    |                     |                   |
| Flexit                   |                    | 1            |                |                  | 1           |          |       | 1    | 1      | 1         |        |         | 1        |                    |                     |                   |
| Proto-lab                |                    | 1            |                |                  | 1           |          |       | 1    |        | 1         |        |         | 1        |                    |                     |                   |
| Idea Incubator           |                    | 1            |                |                  | 1           |          |       | 1    |        | 1         |        |         |          |                    | 1                   |                   |
| Team Lab                 |                    | 1            |                |                  | 1           |          |       |      | 1      | 1         |        |         | 1        |                    |                     |                   |
| Inner Sanctum            |                    | 1            |                |                  | 1           |          |       |      | 1      | 1         |        |         | 1        |                    |                     |                   |

|                            |  |  |   |   |   |  |  |  |   |   |  |  |   |  |  |
|----------------------------|--|--|---|---|---|--|--|--|---|---|--|--|---|--|--|
| Work Process Neighborhood  |  |  | 1 | 1 | 1 |  |  |  | 1 | 1 |  |  | 1 |  |  |
| Innovation Neighborhood    |  |  | 1 | 1 | 1 |  |  |  | 1 | 1 |  |  | 1 |  |  |
| Communication Neighborhood |  |  | 1 | 1 | 1 |  |  |  | 1 | 1 |  |  | 1 |  |  |
| Learning Neighborhood      |  |  | 1 | 1 | 1 |  |  |  | 1 | 1 |  |  | 1 |  |  |

## Appendix D: Questionnaire

| ID     | Question  | Response Scale  |
|--------|---|---|
| Q00    | "Do you have time to answer a few questions about the past NN minutes?"   | 1 = "Yes"   5 = "No; ask me later"  |
| Q01    | "How much of your time, for the past NN minutes, were you doing work related activities?"                         | 1 = "None" → 4 = "All"  |
| Q02    | "Where were you?"   | 1: Steelcase Campus (GrRapids)<br>2: Other Workplace<br>3: In Transit<br>4: Public Place<br>5: Home |
| Q03    | "Will you work any more, before you go to sleep for the night?"   | 1 = "Yes"   5 = "No"  |
| Q04*   | "Did you feel that, during this time, your environment accommodated your needs?"                                  | 1 = "no, the environment made things difficult" → 4 = "yes, the environment met my needs perfectly" |
| Q05*   | "How much of this time involved independent activity, versus group activity?"                                     | 1 = "all independent" → 4 = "all group activity"  |
| Q06**  | "How much of this group activity involved presentations?"   | 1 = "none" → 4 = "all"  |
| Q07**  | "How much of this group activity was virtual (involved electronic communications, including messaging or email)?" | 1 = "all virtual" → 4 = "all in person"   |
| Q08**  | "During this time, did you brainstorm?"   | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q09**  | "My activity during this time was mainly?"  | 1 = "work" → 4 = "social"   |
| Q10*** | "During this time, did you do any writing tasks (by hand or on a computer)?"                                      | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q11*** | "For your activities during this time, did you need to be isolated?"  | 1 = "no, anyone could have taken part" → 4 = "yes, I needed to have my own space"                   |
| Q12*** | "During this time, did you do any analytical or design tasks?"  | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q13*** | "During this time, did you do any organizing of your digital or physical space?"                                  | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q14*** | "How well could you concentrate during this time?"  | 1 = "not well at all" → 4 = "very well"   |



|          |   |   |
|----------|---|---|
| Q15****  | "During this time, how effective was communication between people?"             | 1 = "not effective at all" → 4 = "very effective"   |
| Q16****  | "Did you learn much?"   | 1 = "no; not at all" → 4 = "yes; a lot"   |
| Q17*     | "How did your activity, during this time, affect your stress levels?"           | 1 = "decreased stress" → 4 = "increased stress"   |
| Q18*     | "During this time, did you accomplish much, in terms of your individual tasks?" | 1 = "no; none" → 4 = "yes; lots"  |
| Q19*     | "Are you more or less energized for future tasks?"                              | 1 = "not energized" → 4 = "very energized"  |
| Q20*     | "How valuable was your activity, during this time, to you?"                     | 1 = "a waste of time" → 4 = "highly valuable"   |
| Q21***** | "Was yesterday a busy work day?"  | 1 = "much less than my average" → 4 = "much more than my average"                                   |
| Q22***** | "Where did you do the most work, yesterday?"                                    | 1: Steelcase Campus (GrRapids)<br>2: Other Workplace<br>3: In Transit<br>4: Public Place<br>5: Home |
| Q23***** | "What was your overall stress level, as related to work, yesterday?"            | 1 = "much lower than my average" → 4 = "much higher than my average"                                |
| Q24***** | "How productive were you, yesterday?"   | 1 = "much less than my average" → 4 = "much more than my average"                                   |
| Q25***** | "How creative were you, yesterday?"   | 1 = "much less than my average" → 4 = "much more than my average"                                   |
| Q26***** | "How would you rate your mood, now?"  | 1 = "in low spirits" → 4 = "in high spirits"  |

\*if (response[Q01]!=1)

\*\*if (response[Q01] != 1 && response[Q05] > 1)

\*\*\*if (response[Q01] != 1 && response[Q05] < 5)

\*\*\*\*if (response[Q01] != 1 && response[Q05] > 1 && response[Q02] != 3)

\*\*\*\*\*previous day queries

The conditional branching strategy is simply designed to remove irrelevant questions from the query. If a subject indicates that they engaged entirely in individual or group activity, through their response to early questions, then questions about group or individual activity, respectively, are omitted from the instance of the questionnaire.

## Appendix E: COUHES Approval

**MIT** Committee On the Use of Humans as  
Experimental Subjects

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
77 Massachusetts Avenue  
Cambridge, Massachusetts 02139  
Building E 25-143B  
(617) 253-6787

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**To:** Kent Larson  
NE18-4FL  
**From:** Leigh Finn, Chair  
COUHES  
**Date:** 03/15/2007  
**Committee Action:** Approval  
**Committee Action Date** 03/15/2007

**COUHES Protocol #** 0703002146  
**Study Title** Understanding Behavior with Ubiquitous Computing for Workplace Design Tools  
**Expiration Date** 03/14/2008

The above-referenced protocol has been APPROVED following Full Board Review by the Committee on the Use of Humans as Experimental Subjects (COUHES).

If the research involves collaboration with another institution then the research cannot commence until COUHES receives written notification of approval from the collaborating institution's IRB.

It is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date. Please allow sufficient time for continued approval. You may not continue any research activity beyond the expiration date without COUHES approval. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study termination.

**Adverse Events:** Any serious or unexpected adverse event must be reported to COUHES within 48 hours. All other adverse events should be reported in writing within 10 working days.

**Amendments:** Any changes to the protocol that impact human subjects, including changes in experimental design, equipment, personnel or funding, must be approved by COUHES before they can be initiated.

Prospective new study personnel must, where applicable, complete training in human subjects research and in the HIPAA Privacy Rule before participating in the study.

**CONSENT TO PARTICIPATE IN  
NON-BIOMEDICAL RESEARCH**

Understanding Behavior with Ubiquitous Computing for Workplace Design Tools

You are asked to participate in a research study conducted by the following researchers from the Department of Architecture at the Massachusetts Institute of Technology (M.I.T.):

Kenneth Cheung, Research Assistant, Architecture  
Kent Larson, Principal Research Scientist, Architecture  
Dr. Stephen Intille, Research Scientist, Architecture  
Jennifer Beaudin, Research Scientist, Media Lab  
Emmanuel Munguia-Tapia, Research Assistant, Media Lab  
Giles Phillips, Research Assistant, Architecture  
Manu Gupta, Research Assistant, Media Lab

You were selected as a possible participant in this study because:

- You are at least 18 years of age
- You work in the designated workplace where the study will be conducted
- You have an interest in the subject of the study

You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

• **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. Your participation or non-participation in this study will have no effect on your employee status. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

• **PURPOSE OF THE STUDY**

Architects and designers currently lack the tools to understand whether the spaces that they design actually work as intended. A designer who wishes to measure how people use a space has limited options. One is to use costly, time consuming, and invasive direct observation. Another is to use surveys, which may not accurately capture certain types of information. The aim of this study is to test new technologies that may help architects and designers plan and evaluate office layouts. The technologies we will

test will attempt to automatically record where and how often typical workplace activities occur throughout the office space. Examples of the activities for which we will be collecting data include a group meetings and individual work on organizational tasks.

The technologies that will be evaluated and refined through this study have the potential to help architects and designers design more supportive work environments.

- **PROCEDURES**

If you volunteer to participate in this study, we would ask you to do one or more of the following things:

1. Have infrared motion detecting sensor devices installed in your workplace for approximately thirty days. These sensors register the motion of people in a discrete area of space, without recording identity information.

For the purposes of this study, one sensor per approximately forty square feet of floor area (about the size of one person's desk area) will be temporarily installed throughout your workplace (office). These sensors, called MITes (MIT environmental sensors) were designed at MIT, and have been previously used in studies regarding home activity and healthcare. Additionally, commercial bluetooth beacons will be installed throughout your workplace, at a density of about one per work space (office/desk). These will be placed in convenient locations, where they are out of the way of your normal activities.

The MITes will be placed or taped in easily identifiable locations on the ceiling. They will not interfere with your daily activities, and will not disrupt any existing wireless communication (wireless Internet, cordless phones, mobile phones). These sensors only measure whether or not an object, such as a person, is moving underneath them within a 6'x6' area. These sensors wirelessly transmit information to a nearby computer that saves and timestamps the sensor activations in a coded form. If the location of a particular infrared sensor or beacon makes you uncomfortable, it will be removed.

2. Continuously carry a mobile phone that you will be provided with, and answer questions presented to you on the phone. You will do this for about thirty days during the experiment. The phone will beep and/or vibrate every time you change location, or every two hours, depending on which is more frequent, at which time a survey will be presented. You can answer the questions by pushing buttons on the keypad and sometimes by leaving a voice message. The survey will take between a few seconds to 1-2 minutes to complete. You will be able to mute/ignore the device if you are busy, but to the best of your ability you will be expected to answer the surveys. This self-reported activity data will be compiled and only anonymous meta-data will be used in research publications. A list of questions that will be asked is provided in Appendix A.

During the experiment period, this mobile phone will be running an application that simply detects whether or not a bluetooth beacon is nearby. It will do this by using wireless “beacons” installed throughout your office. The bluetooth beacons will be placed in or taped to convenient locations around the designated study area. As commercial devices, being employed for their intended purpose, these will not disrupt any existing communications. If the mobile phone is within about ten feet of a beacon location, the phone will record this information. These data will be used to determine how people use spaces and when gatherings or meetings occur. Sometimes the survey questions will change based upon your proximity to the beacons and/or information on space usage gathered from the infrared devices. If you agree to carry one of these devices, you will be asked to carry the device throughout the study period as much as possible, and will be free to use the device as a normal mobile phone at all times. The positioning system will only be functional in the designated study area.

These mobile devices with indoor positioning and experience sampling systems will be used to make a generalized meta-report of all of the participants' self-reported workplace activities to be combined with data collected from the sensor systems that measure how the participants occupy and move throughout the designated study area. The experience sampling system can also be “muted” for any amount of time, to avoid disruption, or you can turn off or stop carrying the device.

At the end of the study, you will have the option of keeping the mobile phones for personal use.

3. Allow the survey data and position data to be sent to MIT for analysis. The data will be stripped of participant identity. The data will be coded in such a way that that it will not be possible for your supervisor or others at your workplace to gather information about your whereabouts or activities during or after the study.
4. Along with your participation in these procedures, you may be asked to complete a debriefing interview at the end of the experiment. During this interview, you may decline to answer any or all questions.

#### • **POTENTIAL RISKS AND DISCOMFORTS**

During the course of this study, if you are participating in the data collection procedure, you may at times feel uncomfortable about having data collected about your activities. You may also feel stressed by the repeated survey prompts from the mobile phone. If you are uncomfortable at any time, you may: 1) not answer the survey, 2) turn off the mobile phone, or 3) not carry the mobile phone with you. If you wish to discontinue participation, you may withdraw from the study at any time.

If a particular infrared or Bluetooth beacon sensor makes you uncomfortable, it will be removed.

- **POTENTIAL BENEFITS**

By participating in this study, you may learn about novel technologies under development. You may also gain a deeper appreciation of the richness of your everyday activities and how they are supported by your workplace setting.

We anticipate that this study will help us to develop tools for architects and designers so that they can create better workspaces that increase employee satisfaction and productivity.

- **PAYMENT FOR PARTICIPATION**

We appreciate your courtesy in having the sensors in your workplace for the study period and for participating in the experience sampling tasks. As compensation for participation in activity #2, you may use the provided mobile phones and data contracts for personal purposes, including email and web browsing, for the duration of the study. As a participant in the study, we are happy to provide you with follow up information regarding the results of the study and engage in any related discussion about workplace practices.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

Your responses and sensor data will be referenced by an ID number in order to protect your identity. A study enrollment log will be kept that will include participants' unique identification numbers, names, contact information, and enrollment data. This log will be stored in a locked cabinet in the investigators' office and will be destroyed 1 year after the completion of the study.

When the results of the research are published or discussed at conferences, no information will be included that would reveal your identity. Your name will not in any way be associated your data. Once your data is anonymized, it may be shared with other researchers for future studies.

The investigators at MIT are acting as a separate party to ensure the confidentiality of the data, particularly personal location and activity information gathered by the mobile phone based positioning system. No one except for the MIT investigators will have access to this information before it is anonymized and aggregated. Information that may be associated directly with you will not be shared with individuals at your workplace, regardless of their relationship to you or their role in the research project. No other modifications will be made to the phone and your phone calls, phone-based email communications, and personal use of the phone will not be recorded or exposed. Investigators may take still photographs of your workplace environment.

If you do not wish to have pictures taken of you or your workplace environment, you may still participate in this study without prejudice. The photographs will only be used by the investigators for the data analysis tasks of the study and to document that work in academic publications. The media will be under the sole control of the investigators and will be stored in a location accessible only to the investigators. After the investigators have analyzed the results, prior to showing any images in academic and peer-reviewed papers, or anywhere else, they will use standard methods to manipulate the media to protect your identity, such as blurring the face. Any media that cannot be appropriately anonymized will be destroyed within one year after completion of the study.

Please indicate your consent to have still photography, during the sensor installation and/or post-study interview, by initialing below:

Photo Consent for Sensor Installation: \_\_\_\_\_ Decline: \_\_\_\_\_

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact

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- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

“In the unlikely event of physical injury resulting from participation in this research you may receive medical treatment from the M.I.T. Medical Department, including emergency treatment and follow-up care as needed. Your insurance carrier may be billed for the cost of such treatment. M.I.T. does not provide any other form of compensation for injury. Moreover, in either providing or making such medical care available it does not imply the injury is the fault of the investigator. Further information may be obtained by calling the MIT Insurance and Legal Affairs Office at 1-617-253 2822.”

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143b, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

**SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE**

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

\_\_\_\_\_  
Name of Subject

\_\_\_\_\_  
Name of Legal Representative (if applicable)

\_\_\_\_\_  
Signature of Subject or Legal Representative

\_\_\_\_\_  
Date

**SIGNATURE OF INVESTIGATOR**

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

\_\_\_\_\_  
Signature of Investigator

\_\_\_\_\_  
Date

# **Would you like to participate in a study to help researchers understand the relationship between design and behavior?**

Researchers from the Department of Architecture at the Massachusetts Institute of Technology (M.I.T.) would like to conduct a study on understanding behavior with ubiquitous computing tools.

Kenneth Cheung, Research Assistant, Architecture

## **Does the following describe you?**

- You are at least 18 years of age.
- You work in the designated workplace where the study will be conducted (here).
- You have an interest in workplace design, and the effect of environment on human behavior.

## **If so, we're looking for volunteers!**

If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. Your participation or non-participation in this study will have no effect on your employee status. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

### **• WHAT FOR?**

Architects and designers currently lack the tools to understand whether the spaces that they design actually work as intended. A designer who wishes to measure how people use a space has limited options. One is to use costly, time consuming, and invasive direct observation. Another is to use surveys, which may not accurately capture certain types of information. The aim of this study is to test new technologies that may help architects and designers plan and evaluate office layouts. The technologies we will test will attempt to automatically record where and how often typical workplace activities occur throughout the office space. Examples of the activities for which we will be collecting data include a group meetings and individual work on organizational tasks.

The technologies that will be evaluated and refined through this study have the potential to help architects and designers design more supportive work environments.

### **• WHAT WOULD I HAVE TO DO?**

If you volunteer to participate in this study, we would ask you to do one or more of the following things:

5. Have infrared motion detecting sensor devices installed in your workplace for \_\_\_ days. These sensors register the motion of people in a discrete area of space, without recording identity information.

For the purposes of this study, one sensor per approximately forty square feet of floor area (about the size of one person's desk area) will be temporarily installed throughout your workplace (office). These sensors, called MITes (MIT environmental sensors) were designed at MIT, and have been previously used in studies regarding home activity and healthcare. Additionally, commercial bluetooth beacons will be installed throughout your workplace, at a density of about one per work space (office/desk). These will be placed in convenient locations, where they are out of the way of your normal activities.

The MITes will be placed or taped in easily identifiable locations on the ceiling. They will not interfere with your daily activities, and will not disrupt any existing wireless communication (wireless Internet, cordless phones, mobile phones). These sensors only measure whether or not an object, such as a person, is moving underneath them within a 6'x6' area. These sensors wirelessly transmit information to a nearby computer that saves and timestamps the sensor activations in a coded form. If the location of a particular infrared sensor or beacon makes you uncomfortable, it will be removed.

6. Continuously carry a mobile phone that you will be provided with, and answer questions presented to you on the phone. You will do this for \_\_\_ days during the experiment. The phone will beep and/or vibrate every time you change location, or every two hours, depending on which is more frequent, at which time a survey will be presented. You can answer the questions by pushing buttons on the keypad and sometimes by leaving a voice message. The survey will take between a few seconds to 1-2 minutes to complete. You will be able to mute/ignore the device if you are busy, but to the best of your ability you will be expected to answer the surveys. This self-reported activity data will be compiled and only anonymous meta-data will be used in research publications. A list of questions that will be asked is provided in [Appendix D].

During the experiment period, this mobile phone will be running an application that simply detects whether or not a bluetooth beacon is nearby. It will do this by using wireless "beacons" installed throughout your office. The bluetooth beacons will be placed in or taped to convenient locations around the designated study area. As commercial devices, being employed for their intended purpose, these will not disrupt any existing communications. If the mobile phone is within about ten feet of a beacon location, the phone will record this information. These data will be used to determine how people use spaces and when gatherings or meetings occur. Sometimes the survey questions will change based upon your proximity to the beacons and/or

information on space usage gathered from the infrared devices. If you agree to carry one of these devices, you will be asked to carry the device throughout the study period as much as possible, and will be free to use the device as a normal mobile phone at all times. The positioning system will only be functional in the designated study area.

These mobile devices with indoor positioning and experience sampling systems will be used to make a generalized meta-report of all of the participants' self-reported workplace activities to be combined with data collected from the sensor systems that measure how the participants occupy and move throughout the designated study area. The experience sampling system can also be "muted" for any amount of time, to avoid disruption, or you can turn off or stop carrying the device.

At the end of the study, you will have the option of keeping the mobile phones for personal use.

7. Allow the survey data and position data to be sent to MIT for analysis. The data will be stripped of participant identity. The data will be coded in such a way that it will not be possible for your supervisor or others at your workplace to gather information about your whereabouts or activities during or after the study.
8. Along with your participation in these procedures, you may be asked to complete a debriefing interview at the end of the experiment. During this interview, you may decline to answer any or all questions.

- **WHY MIGHT I NOT WANT TO PARTICIPATE?**

During the course of this study, if you are participating in the data collection procedure, you may at times feel uncomfortable about having data collected about your activities. You may also feel stressed by the repeated survey prompts from the mobile phone. If you are uncomfortable at any time, you may: 1) not answer the survey, 2) turn off the mobile phone, or 3) not carry the mobile phone with you. If you wish to discontinue participation, you may withdraw from the study at any time.

If a particular infrared or Bluetooth beacon sensor makes you uncomfortable, it will be removed.

- **WHAT DO I GET?**

By participating in this study, you may learn about novel technologies under development. You may also gain a deeper appreciation of the richness of your everyday activities and how they are supported by your workplace setting.

We anticipate that this study will help us to develop tools for architects and designers so that they can create better workspaces that increase employee satisfaction and productivity.

We appreciate your courtesy in having the sensors in your workplace for the study period and for participating in the experience sampling tasks. As compensation for participation in activity #2, you may use the provided mobile phones and data contracts for personal purposes, including email and web browsing, for the duration of the study. As a participant in the study, we are happy to provide you with follow up information regarding the results of the study and engage in any related discussion about workplace practices.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law.

- **WHO DO I CONTACT?**

If you would like to volunteer, or have any questions or concerns about the research, please feel free to contact:

Kenneth Cheung  
Research Assistant, MIT Dept. Of Architecture  
617-452-5604, kccheung@mit.edu

Appendix H: ANOVA of Question Responses by Environment Type

|     |                | SS       | df  | Mean Square | F     | Sig. |
|-----|----------------|----------|-----|-------------|-------|------|
| q00 | Between Groups | 6.832    | 2   | 3.416       | .933  | .394 |
|     | Within Groups  | 1021.083 | 279 | 3.660       |       |      |
|     | Total          | 1027.915 | 281 |             |       |      |
| q01 | Between Groups | 11.861   | 2   | 5.931       | 5.859 | .003 |
|     | Within Groups  | 182.215  | 180 | 1.012       |       |      |
|     | Total          | 194.077  | 182 |             |       |      |
| q04 | Between Groups | 5.370    | 2   | 2.685       | 3.717 | .026 |
|     | Within Groups  | 123.504  | 171 | .722        |       |      |
|     | Total          | 128.874  | 173 |             |       |      |
| q05 | Between Groups | 18.167   | 2   | 9.083       | 3.642 | .028 |
|     | Within Groups  | 426.500  | 171 | 2.494       |       |      |
|     | Total          | 444.667  | 173 |             |       |      |
| q06 | Between Groups | 21.955   | 2   | 10.977      | 6.560 | .002 |
|     | Within Groups  | 138.894  | 83  | 1.673       |       |      |
|     | Total          | 160.849  | 85  |             |       |      |
| q07 | Between Groups | 2.780    | 2   | 1.390       | .692  | .503 |
|     | Within Groups  | 166.720  | 83  | 2.009       |       |      |
|     | Total          | 169.500  | 85  |             |       |      |
| q08 | Between Groups | 9.013    | 2   | 4.507       | 2.104 | .128 |
|     | Within Groups  | 177.789  | 83  | 2.142       |       |      |
|     | Total          | 186.802  | 85  |             |       |      |
| q09 | Between Groups | 1.096    | 2   | .548        | .879  | .419 |
|     | Within Groups  | 51.752   | 83  | .624        |       |      |
|     | Total          | 52.849   | 85  |             |       |      |
| q10 | Between Groups | 5.332    | 2   | 2.666       | 1.843 | .167 |
|     | Within Groups  | 83.881   | 58  | 1.446       |       |      |
|     | Total          | 89.213   | 60  |             |       |      |
| q11 | Between Groups | 4.993    | 2   | 2.497       | 1.089 | .339 |
|     | Within Groups  | 327.966  | 143 | 2.293       |       |      |
|     | Total          | 332.959  | 145 |             |       |      |
| q12 | Between Groups | 8.109    | 2   | 4.055       | 2.063 | .131 |
|     | Within Groups  | 281.048  | 143 | 1.965       |       |      |
|     | Total          | 289.158  | 145 |             |       |      |



|     |                |         |     |        |       |      |
|-----|----------------|---------|-----|--------|-------|------|
| q13 | Between Groups | 38.301  | 2   | 19.151 | 9.531 | .000 |
|     | Within Groups  | 287.322 | 143 | 2.009  |       |      |
|     | Total          | 325.623 | 145 |        |       |      |
| q14 | Between Groups | 6.800   | 2   | 3.400  | 2.570 | .080 |
|     | Within Groups  | 189.207 | 143 | 1.323  |       |      |
|     | Total          | 196.007 | 145 |        |       |      |
| q15 | Between Groups | 6.288   | 2   | 3.144  | 3.402 | .038 |
|     | Within Groups  | 76.701  | 83  | .924   |       |      |
|     | Total          | 82.988  | 85  |        |       |      |
| q16 | Between Groups | 9.878   | 2   | 4.939  | 3.114 | .050 |
|     | Within Groups  | 131.657 | 83  | 1.586  |       |      |
|     | Total          | 141.535 | 85  |        |       |      |
| q17 | Between Groups | 9.503   | 2   | 4.751  | 2.769 | .066 |
|     | Within Groups  | 293.446 | 171 | 1.716  |       |      |
|     | Total          | 302.948 | 173 |        |       |      |
| q18 | Between Groups | 7.275   | 2   | 3.638  | 1.839 | .162 |
|     | Within Groups  | 338.202 | 171 | 1.978  |       |      |
|     | Total          | 345.477 | 173 |        |       |      |
| q19 | Between Groups | 12.810  | 2   | 6.405  | 4.178 | .017 |
|     | Within Groups  | 262.155 | 171 | 1.533  |       |      |
|     | Total          | 274.966 | 173 |        |       |      |
| q20 | Between Groups | 4.310   | 2   | 2.155  | 2.245 | .109 |
|     | Within Groups  | 164.155 | 171 | .960   |       |      |
|     | Total          | 168.466 | 173 |        |       |      |



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