Exploring building adaptability based on user needs

Integrating ubiquitous computing in a campus building to optimize learning environments

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ABSTRACT

In response to students' evolving demands, campus buildings are increasingly re-structured to serve as informal learning spaces integrating sensors and automated systems within learning environments. This research uses the Lab42 building at UvA Science Park as a case study to explore the impact on students of integrating ubiquitous computing for optimal learning activities. By analyzing student behavior within the building and their interactions with a prototype design solution, the findings provide valuable insights for faculty staff, offering potential implications for the design of future campus buildings and spaces.

KEYWORDS

Human-Building interaction, Ubiquitous computing, Persuasive technology, Living lab, Smart buildings, User-centered design.

METADATA

Thesis Design for the fullfiment of the *Master Thesis* for the Master Information Studies: *Information Systems (IS)*.

Institute: Informatics Institute
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1 INTRODUCTION

In response to the increase in student enrollments and their evolving needs, universities are transforming campus buildings into informal learning spaces to encourage students to spend more time on campus. This transformation is facilitated, in part, by the growing integration of sensors and automated systems within buildings. These technologies aim to regulate comfort in a multi-dimensional approach encapsulated in thermal, respiratory, visual, and acoustic dimensions.

However, the prevailing approach of retrofitting sensors onto existing buildings leaves students with a perceived lack of control and are often expected to conform to the building rather than experiencing spaces that adapt to their needs. This creates an interplay between students' needs and requirements, built environments, and computing technologies.

This thesis focuses on understanding user behavior and needs through in-the-wild studies and prototyping of various ubiquitous computing devices and the evaluation of their effectiveness with the overall goal of gathering insights into students' needs, to enhance their learning spaces and move towards adaptive smart buildings.

1.1 Research questions

In order to research the enhancement of informal learning spaces through ubiquitous computing: the following main research question is formulated:

How can ubiquitous computing impact student behavior to significantly enhance the quality of informal learning spaces and facilitate an optimal learning environment?

To effectively answer this main research question, this research is guided by the following supporting sub-questions that also serve as objectives to delineate the necessary knowledge:

- **RQ1:** *What are the characteristics, intentions, and goals of the students entering the building?*
- **RQ2:** *How do students of the building currently define and rate their comfort concerning subjective parameters of the building?*
- **RQ3:** *What sensory data about students and the environment is currently being collected and should this be enhanced?*
- **RQ4:** *How can ubiquitous computing devices nudge students into certain desired behavior?*
- **RQ5:** *Is there a difference in user behavior pre-installation and post-installation of the computing devices?*

As outlined in the *related work* existing research has explored human-building interaction, the field of persuasive technology, data physicalization, and informal learning spaces. While research on defining comfort within indoor buildings and gathering and analyzing sensory data is prevalent, there is a gap in understanding user behavior and their subjective needs. Moreover, limited research exists on how design solutions can empower users, providing them with control and enabling spaces (including buildings in general) to adapt to user needs.

1.2 Problem statement

Modern campus buildings (e.g. Lab42) are increasingly equipped with sensors and automated systems to regulate occupants' comforts, governed by parameters established through generic building policies and faculty staff Unfortunately, students in these buildings often encounter limitations in exerting personal control over their comfort and data gathered by these systems is invisible to the user and choices the system makes are not transparent.

This adaptation implies that buildings should embody empathy [12] and be adaptive (e.g. responsive to human signals such as emotions) with a focus on fostering user interaction with the environment. Researching to understand students' subjective needs, experiences, and behavior, coupled with a human-centric design approach, has the potential to elevate occupants' well-being and create optimal learning spaces. Furthermore, it provides valuable insights to faculty staff in making decisions to optimally arrange learning spaces and inform architecture and interior design studios on making decisions about structuring spaces and integrating computing technologies within built environments.

1.3 Lab42 building

This study will be conducted in association with the Digital Interactions Lab [1] and will utilize the recently opened Lab42 [2] building at the UvA Amsterdam Science Park [3] as its primary case study. Lab42 is an energy-neutral, flexible, and adaptable faculty building that facilitates collaborations among students, researchers, and businesses [4]. The buildings's layout is strategically organized into different zones, each serving various functions, ranging from quiet individual work to spaces that allow for collaborative work. The overarching interior theme in the design revolves around 'tech' and 'nature' aiming to cultivate a fresh, light, and warm comfortable ambiance. Sensing devices are installed throughout the building to automatically adjust lighting, air, and temperature [14].

2 RELATED WORK

The desk research and literature review span several key domains within the field of human-computer interaction. Initially, a theoretical framework is established with the notion of human-building interaction, data physicalization, and ubiquitous computing. Subsequently, the focus narrows down to more specific aspects relevant to the research context delving into persuasive technology and its possible application within learning environments.

2.1 Human-building Interaction

Buildings increasingly incorporate new forms of interactivity, which means new inherent connections between 'people', 'built environments', and 'computing' in an emergent research area called Human-Building Interaction (HBI) [1]. This research area is dedicated to exploring the design of built environments that may incorporate computing to varying degrees. Understanding how people use different spaces in a building can inform design interventions aimed at improving the utility of the space [15]. Current research highlights that a significant portion of the data collected by these computing devices within buildings, such as sensors and cameras, is not readily apparent to visitors and residents, and buildings are not optimally architected to allow computing devices to be integrated within the environment.

2.2 Comfort within buildings

Comfort is achieved in interaction with the environment and is represented in four respective dimensions; thermal, respiratory, visual, and acoustic [3]. Comfort can be studied and designed as an interactive experience with the built environment itself [2]. Indoor Environmental Quality (IEQ) indexes serve as metrics for assessing comfort, with Post-Occupancy Evaluation (POE) being employed to gauge occupants' perceived comfort. In current scenarios, technology is typically retrofitted onto a new or existing building and users indicate a perceived lack of control and engagement with these systems, primarily because many automated buildings operate based on arbitrarily set parameters.

2.3 Persuasive technology

Ubiquitous computing (ubicomp) facilitates new modes of computing, sensing, and actuation seamlessly integrated with physicality. The primary aim of ubiquitous computing devices is to seamlessly blend into the environment, essentially making computing devices 'disappear'[16]. Recent advancements in technology, such as lower-cost hardware (per Moore's Law), a diverse array of sensors and actuators, and improved protocol and communication technologies, have improved the capabilities of ubicomp devices. Devices are frequently employed as persuasive technology, strategically designed to gently nudge individuals towards behavior change leveraging the emerging notion of pervasive sensing to subtly enhance users' awareness regarding the impacts of their decisions [13]. This integration of ubicomp and persuasive design serves as a powerful tool in calmly extending users' awareness, helping users understand the consequences of their actions, and gaining insight into their behavior. [17].

2.4 Data physicalization

The research domain known as data physicalization has emerged as a notable area of study, emphasizing the creation of physical data visualizations making the invisible tangible and interactible by encoding data in physical artifacts [8]. This shift from focusing on individual artifacts to a broader environmental context facilitates the physical embodiment of computing. Data physicalization has the potential to positively influence the perception and exploration of data, presenting distinct advantages over traditional 'screen-focused' data representations, such as 2D canvas display [9].

2.5 Informal Learning spaces

Universities are actively restructuring and redesigning campus buildings to the notion of 'sticky campuses' [6] aimed at enticing students to spend more time on campus. Primarily moving from strictly learning environments (e.g. lecture halls, classrooms) to more informal learning (e.g. collaborative spaces) spaces redefining universities as dynamic learning environments. The establishment of these informal learning spaces, a significant aspect of the Lab42 building, prompts crucial inquiries into student behaviors and the nature of 'learning' [5]. Notably, there is a growing body of research that delves into the relationship between the arrangement and control of learning spaces and student learning activities [7].

3 METHODOLOGY

Integration of user studies throughout the process and a system of data collection are the main focus of this research. Methodologies are picked that are project-oriented and are part of in-the-wild

[1] https://uva-dilab.com/
[2] https://lab42.uva.nl/
[3] https://www.amsterdamsciencepark.nl/

studies to study user behaviour and space usage and combine it with data gathered from using Internet of Things (IoT) devices on which both data cleaning, transformation and analysis are performed. In the end a prototype of a persuasive technology will be manufactured and usability tested to see possible change in user behaviour pre-installation and post-installation. With the goal to have a design informed by data and use design as a probing (data collection) tool.

3.1 User studies (elicitation study)

Gather information about users within the building. There emotional state. Most likely these will be surveys handout throughout the thesis projects. Potential one-one interviews will be conducted with more open ended questions (open field questionnaire) about further comfort levels of specific users. This includes methods such as creating *personas, empathy maps, MoSCoW* and gives an overview of user needs and current behaviour of users within the building. These findings will be evaluated based on:

- What are intentions of students entering the building?

3.2 Space behaviour

With sensing devices scattered throughout the Lab42 building. This includes methods such as *field trails, customer journeys and observation.* These findings will be evaluated based on:

- What is current space usage within the building?

3.3 Prototyping

This includes methods such as creating *ideation, proof of concept, requirements list and provocative prototyping* to create a design solution for behaviour change with the notion of calm technology (e.g. engage users in preventive action with minimised interruption cost) which can be further tested. Usability testing and data analysis of the prototype can be comparative and gives insight in how well user behaviour changes pre-installation and post-installation. Prototyping will most likely consists of three components related to the design challenge:

1) Sensing device using a microcontroller (Ubicomp): sensory data that will measure specific user behaviour in a couple of spaces throughout the building. Most likely created using the ESP32 platform [4]

2) Storage with Realtime API (Back-end): to store the data for persisent storage in a back-end and display visualizations in a front-end dashboard for furhter use. Most likely created with a front-end framework such as Svelte [5] and the GraphQL query language [6].

3) Tangible visualization (Ambient display): some sort of physical tangible data visualization collectively showing the output of the sensory data with the goal of changing behaviour most likely created using the Raspberry Pi [7] or Ardunio [8] platform and visualization will be created using Processing [9].

[4]https://www.espressif.com/en/products/socs/esp32
[5]https://svelte.dev/
[6]https://graphql.org/
[7]https://www.raspberrypi.org/
[8]https://www.arduino.cc/
[9]https://processing.org/

3.4 Existing datasets

There is also existing data about the lab building. The building itself has a spreadsheet of all data collected which has building data about:

- Sound measurement
- Building temperature
- Occupancy

Next to generic building data gather by the building sensors previous studies on the Lab42 performed are a study by Master Student Jan Ramdohr who created a sensig device to get some specific device measurement data [10]. Also a specific survey about users emotion is performed by PhD candidate Shruti Rao and questions were asked pertaining to comfort and emotions across various spaces in the building [11]. These findings will be evaluated based on:

- What paramters are used to adjust the temperature?
- Do outside conditions influence the time spent indoor?

4 RESEARCH OUTPUTS

4.1 Data collection and analysis

As outlined in the methodology section first user studies on space needs to be performed which produce data which will be analyzed as part of the research. This data will be processed using python and jupyper to be cleaned, transformed and mostly to gain interesting insights in space behavior. This will most likely also include analysis of surveys using Python and Jupyter notebooks [10] (e.g. data cleaning, sentiment analysis) and visualization of the data in graphs using visualization libraries such as Seaborn [11].

4.2 Prototype evaluation

The evaluation group will be handed out questionnaires, which will ask the same questions about the visualizations, aiming to get an insight into the perception of the visualizations. The experiment will aim at finding out wether the installation post and pre-installation has any significant effect on changing user behaviour.

5 RISK ASSESSMENT

Although this research is not entirely dependent on the available existing data, since part of the research is to gather data by the researcher, the results will most likely benefit from access and analyzing existing user and building datasets.

5.1 Interview and surveys

If no or not enough interviews can be conducted due to time constraints or unavailable interviewees, there will be a lack of information which leads to an absence of information saturation.

5.2 Building sensory data

Access to data building is not properly exposed or current building data is limited to gather significant data about occupancy. Which means gathering data about the current building is limited. This can be mitagated by enhancing the already existing sensors with

[10]https://jupyter.org/
[11]https://seaborn.pydata.org/

prototype sensing devices to gather data as a proof of concept. Only relying on data is a risk factory and icorrect processing of the data can lead to incorrect evaluation of user behaviour. The data should thus always be cross-referenced with survey data

5.3 Installation

Due to construction or administrative reasons it might not be possible to test the eventual design solution in the building at scale. This needs to be discussed with building faculty staff. This can be mitigated by testing the prototype in a different context to test it's usability.

5.4 Privacy considerations

Sensing and gathering sensory data from users is data collection that users might deem as privacy-invasive. Careful considerations should be made to mitigate these concert and be open and transparent to users what data is being collected and how it's beind processed. Users should be confident that data for this research is gather anonysmouly and only for collective monitoring, so they should not be traced back to individuals users and location.

5.5 Ethical considerations

Since most of this research involves user studies. The data requires the researcher to act with great care, taking appropriate precautions the data is only examined on site within the constraints of the building and UvA faculty. Interacting with users within the building will be confirmed following the code of conduct for the HvA and an application to the ECIS about how data is being stored and gathered has been made. An advice from the committee is still pending.

6 PROJECT PLAN

The thesis project will be fulfilled on a part-time basis. This means that preperation for the project started already early november/december 2023 with concepting and ideation. From around the 8th of january 2024 until 30 june 2024 (submission data of the thesis) this research will be investigated.

The first phase of the project will focus on gathering user data and analysing. The second part of the project will mostly focus on prototyping design solutions and iterating. The third phase of the project will most likely consists of usability testing and evaluation. Please refer to figure 1 for a full weekly overview of task completion.

Ideally this research and the design solutions tested would scale to other university buildings but since the context of those buildings is unclear the scope of this research is defined to the Lab42 building.

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Appendix A GITHUB REPOS

In the spirit of open research, to support reproducibility and enable future work in this problem space the datasets, research notebooks, and prototypes in this work are publicly available on a GitHub organization with the working title 'viszlab' (https://github.com/viszlab) using the MIT License. Several code repositories for different parts of the research can be accessed:

(1) **Prototype**. Code and models for the physical prototype. https://github.com/viszlab/prototype
(2) **Datasets**: Datasets and notebooks for data transformation https://github.com/viszlab/datasets

Appendix B PROJECT TIMELINE

Task	January					February			March						
	W1	W2	W3	W4	W5	W6	W7	W8	W10	W11	W12	W13	W14	W15	W16

Figure 1: Gantt Chart of the project timeline

Appendix C BUILDING IMPRESSIONS

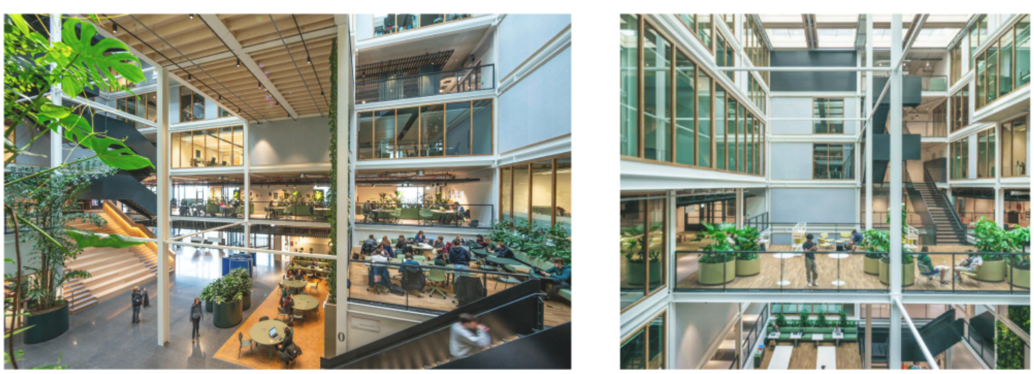

Figure 2: Building impressions photographs