Towards adaptive buildings based on user needs

A persuasive technology approach for enhancing learning spaces

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Danny de Vries
danny.de.vries@student.uva.nl
University of Amsterdam
Amsterdam, The Netherlands

Dr. Hamed Seiied Alavi PhD
h.alavi@uva.nl
University of Amsterdam
Amsterdam, The Netherlands

ABSTRACT

In response to the evolving demands of students campus buildings are increasingly re-structured to function as informal learning spaces. This research addresses the changing needs of students by investigating the transformation of campus buildings into informal learning spaces. Focused on the Lab42 building at UvA Science Park, the research explores the impact of integrating persuasive technology 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 university buildings..

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).*

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Supervisor: Dr. Hamed Seiied Alavi PhD
Mentor: Shruti Rao Ph.D. Candidate

1 INTRODUCTION

As universities respond to the evolving needs of students, a transformation is underway in the restructuring of spaces. This redefines University buildings as informal learning spaces encouraging students to spend more time on campus. One aspect is the increasing use of sensors and automated systems that are equiped within buildings 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 engagement, as students are expected to adapt to the building rather than the other way around. This creates an interplay between user needs, built environments, and computing technologies.

Recognizing the evolving needs of students this thesis will research the intersection between user behaviour, persuasive technology and ubiquitous computing to enhance informal learning spaces by the integration of pervasive sensing to enhance students awareness about their surroundings for optimal learning activity.

1.1 Research questions

In order to achieve this, the following main research question is formulated:

How can persuasive technology combining user data and ubiquitous computing design impact user behavior to significantly enhance the quality of informal learning spaces to facilitate an optimal learning environment?

To be able to answer this research question the following supporting sub-questions, which also act as objectives to describe which knowledge needs to be acquired to be able to answer the main reserach question, are formulated:

- **RQ1:** *What are the characteristics, intentions and goals of the users entering the building? (descriptive)*
- **RQ2:** *How do users of the building currently define and rate their personal comfort in relation to the building? (defining)*
- **RQ3:** *What sensory data about users and the environment is currently being collected in the building and can this be enhanced? (defining)*
- **RQ4:** *How can a ubiquitous computing device (persuasive technology) nudge users into certain desired behavior? (designing)*
- **RQ5:** *Is there a difference in user-behaviour pre-installation and post-installation of the device?*

As outlined further in the *related work* section research has been done on smart buildings, the field of ubiquitous computing and sensory data has also seen a lot of research especially with the advancement of low-cost hardware components. Less research has been done to give a definition comfort within indoor buildings and many of this research is limited to gathering data and analyzing but not much research is performed on actually measuring user behaviour and if with ambient devices users can be nudged or pushed to take preventive action and if components within a building can be adapter to and change behaviour especially within the niche and focus of this case study; students as a focus group in the context of informal learning environments.

1.2 Problem statement

Buildings are more and more getting equiped with sensors and automated systems that regulate based on general parameters set by policymembers and administrative staff. Users within buildings have limited control to make adjust in terms of their comfort. In short: *the building must adapt to the user instead of the user adapting to the building*. This research specifically helps to efficiently arrange the Lab-42 building and helps faculty staff to make decisions on how to optimally arrange spaces but in general can inform architecture and builders to optimize further university buildings with a focus on informal learning spaces.

1.3 Lab42 building

This research will be performed in association with the *Digital Interactions Lab* and uses the recently (september 2022) opened Lab42 [1] building at the UvA Amsterdam Science Park as a case study. Lab42 is a energy-neutral, flexible and adaptable designed faculty building that facilites partnerships between students, researchers and businesses. [4] The layout aims to feature different zones with varying functionalities, from areas where you can sit quietly and focus on work to spaces that allows for collaborative work. The overarching interior theme in the design is 'tech' and 'nature' aiming to create afresh, light and warm comfortable building. Sensing devices are installed throughout the building to automatically adjust lighting, air, temperature so these can be adjusted for overall improvement of comfort [13].

2 RELATED WORK

The desk research and literature review is related to several focus areas within human-computer interaction. A theoretical framework is first defined with the notion of human-building interaction and ubiquitous computing and then more specific to the use case case of this study related to persuasive technology and learning environments.

2.1 Human-building Interaction

Buildings increasingly incorporate new forms of interactivity, this means new inherent connections between 'people', 'built environments' and 'computing' in an emergent research area called Human-Building Interaction (HBI) [1] and focussed on the design of built environments which 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 that building and inform the design of future buildings [14]. Currently research shows that much of the data collected by devices (e.g. sensors and cameras) are not immediately obvious to visitors and residents.

2.2 Comfort within buildings

Comfort is achieved in interaction with the environments and is represented in four respective dimensions; thermal, respiratory, visual and acoustic [3]. Comfort can be studied and designed as interactive experience with the build environment [2]. Currently Indoor Environmental Quality (IEQ) indexes are being uses as a measurement of comfort and Post-Occupancy Evaluation (POE) to evaluate occupants perceived comfort. In current situations technology is typically retrofitted onto a new or existing building and users indicate a perceived lack of control and engagement with these systems since most are automated buildings set on arbitrarely set parameters.

[1] https://lab42.uva.nl/

2.3 Persuasive technology

Ubiquitous computing (ubicomp) enables new forms and embodiment of computing, sensing and actuation combined with physicality with the goal of computing devices to 'dissapear' within the environment [15]. Recent years have seen several ubicomp enables such as enabling lower-cost hardware (moore's law), more diverse sensors and actuators and better protocol and communication technologies. Ubiquitous computing devices are often used as persuasive technology and designed to nudge people to change their behaviour [12]. These devices and technologies can extend the users awareness in a calm manor about impact of their decisions, through the use of the emerging notion of pervasive sensing [16].

2.4 Data physicalization

The research field known as data physicalization has recently gained traction, it focusses on physical data visualizations making the invisible tangible and interactible by encoding data in physical artifacts [8]. A shift from 'artifact' to 'environment' and thus enables a physical embodiment of computing. Data physicalization illustrates how opportunities, such as positively impacting how we perceive and explore data, compared to 'screen-focussed' (e.g. 2D canvas) data representations [9].

2.5 Informal Learning spaces

Universities are increasingly re-arranging and re-building campus buildings to the notion of 'sticky campusses' [6], the notion to entice 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 learning environments. The creation of these informal learning spaces, which are a large factor in the building of the Lab42 building, raises important questions regarding student behaviours and 'learning'[5] and there is increasing research focussed on the relation between 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 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 [2]

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 [3] and the GraphQL query language [4].

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 [5] or Ardunio [6] platform and visualization will be created using Processing [7].

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 [8] (e.g. data cleaning, sentiment analysis) and visualization of the data in graphs using visualization libraries such as Seaborn [9].

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 prototype sensing devices to gather data as a proof of concept.

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 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

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

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

Appendix B PROJECT TIMELINE

Appendix C BUILDING IMPRESSIONS