DATA PHYSICALIZATION FOR COMMUNICATION OF REAL-TIME LIBRARY OCCUPANCY AT THE UNIVERSITY OF TWENTE: A PARTICIPATORY DESIGN APPROACH

Bachelor of Science Thesis Creative Technology

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Abstract

Recent developments in Internet-of-Things (IoT) technologies have led to the transformation of buildings into smart, data-rich environments. Despite their extensive data collection, the accessibility and utility of this building data is often overlooked by these smart systems, as research and development are mainly focused on enhancing operational management. This research aims to address this gap by exploring innovative interfaces designed to communicate real-time occupancy data to users of smart buildings, specifically within the context of a university library.

The project investigates the requirements and possibilities of a novel communication system that goes beyond traditional digital displays, using the concept of data physicalization to explore opportunities of using spaces and environments as interfaces to communicate real-time library occupancy information. This approach aims to make this building data more accessible and meaningful to students to inform their decision-making process in selecting a study space with real-time occupancy information.

Utilising a mixed-method approach, including a library-wide survey and focus groups with university students, the study identified the user needs and key requirements for an effective occupancy communication system. A participatory design study was performed to facilitate the collaborative creation of concepts for real-time occupancy data physicalizations, leading to the development of a design space to explain the range of possibilities for physicalizing this occupancy data. One physicalization idea that emerged from the workshops was further elaborated upon and specified to provide a detailed outline for future implementation.

The research contributes insights into the requirements and physical design possibilities for communicating real-time occupancy data of the library at the University of Twente. The defined design space offers a framework for future development of data physicalization projects in similar contexts. Moreover, the specification of the selected data physicalization concept exemplifies the practical application of integrating data within physical environments to make data more accessible and meaningful for building occupants.

Acknowledgements

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1 Introduction

This chapter provides the introduction and context for this research project, focusing on library occupancy data and its potential presentation to university students. First, the current state of digital technology integration in smart buildings is examined. Following this, the necessity of this project is explained, demonstrating the existing gap in this field of research. The research questions are stated and finally this chapter presents an outline of the research report.

1.1 Context and relevance

Recent developments in Internet-of-Things (IoT) applications, Building Management Systems (BMS), and Building Information Modelling (BIM) have facilitated the infusion of digital technology in so-called 'smart buildings' [1] [2] [3]. These technologies provide the means and infrastructure to collect and process data about the built environment and occupant behaviour. This data has largely been used for optimising the building environment, focusing on efficient energy consumption, use, and maintenance [4] and more recently for quantifying and optimising the health and wellbeing of the building's occupants [3] [5]. Though much research about these digital integrations is being conducted concerning the technical aspects of systems and Human Building Interaction (HBI), there is still a notable gap in research focused on the development of building-integrated systems that empower occupants [6]. Often, these smart building systems are developed with the objective of assisting operation management and research projects and disregard the potential to make occupants aware of the collected data and its potential use. Therefore, there is a need for research focused on exploring new interfaces that communicate live operational building data to occupants [6].

This research project is developed for a client, the library department of Library, ICT Services & Archive (LISA) at the University of Twente (UT) [7]. The library has implemented sensors to gather information about the number of people present in their building. For a while, people counters at the entrance have been gathering data about the incoming and outgoing students in real-time [8]. This data was necessary during the COVID-19 epidemic, but is now used internally by the library in their decision making about the facility, such as opening hours, cleaning schedules, etc. Additionally, the library has heat sensors present in the project rooms to determine its occupation for energy regulation purposes. Right now, the library facilitates a pilot project in collaboration with Digital Society Institute (DSI) at UT [9] to implement sensors at monitor desks to observe their occupancy. Next to informing the library about a more detailed level of seat occupancy, the project is also used as an example for further implementation at different types of library seats or other facilities on the university campus. Recently, a group of Technical Computer Science (TCS) students from the UT analysed the historical data and utilised it to give meaning to the data and extract certain occupancy patterns of the library building, which is further explained in Section 1.2.

The data gathered in the library facilities is rich in information that is currently used internally for decision making purposes. However, the library sees an opportunity to communicate this information to its main user group, the university students. Therefore, this research project will investigate such a means to facilitate the communication between the library and the students about occupancy data.

1.2 Challenges

Currently, there is not yet a system in place at the UT library that shows occupancy data to the students. The mentioned collaboration between library and the group of TCS students resulted in an online

dashboard on Grafana [10], where the historical and real-time occupancy data from the library is visualised, allowing the library to get valuable insights (see Figure 1).

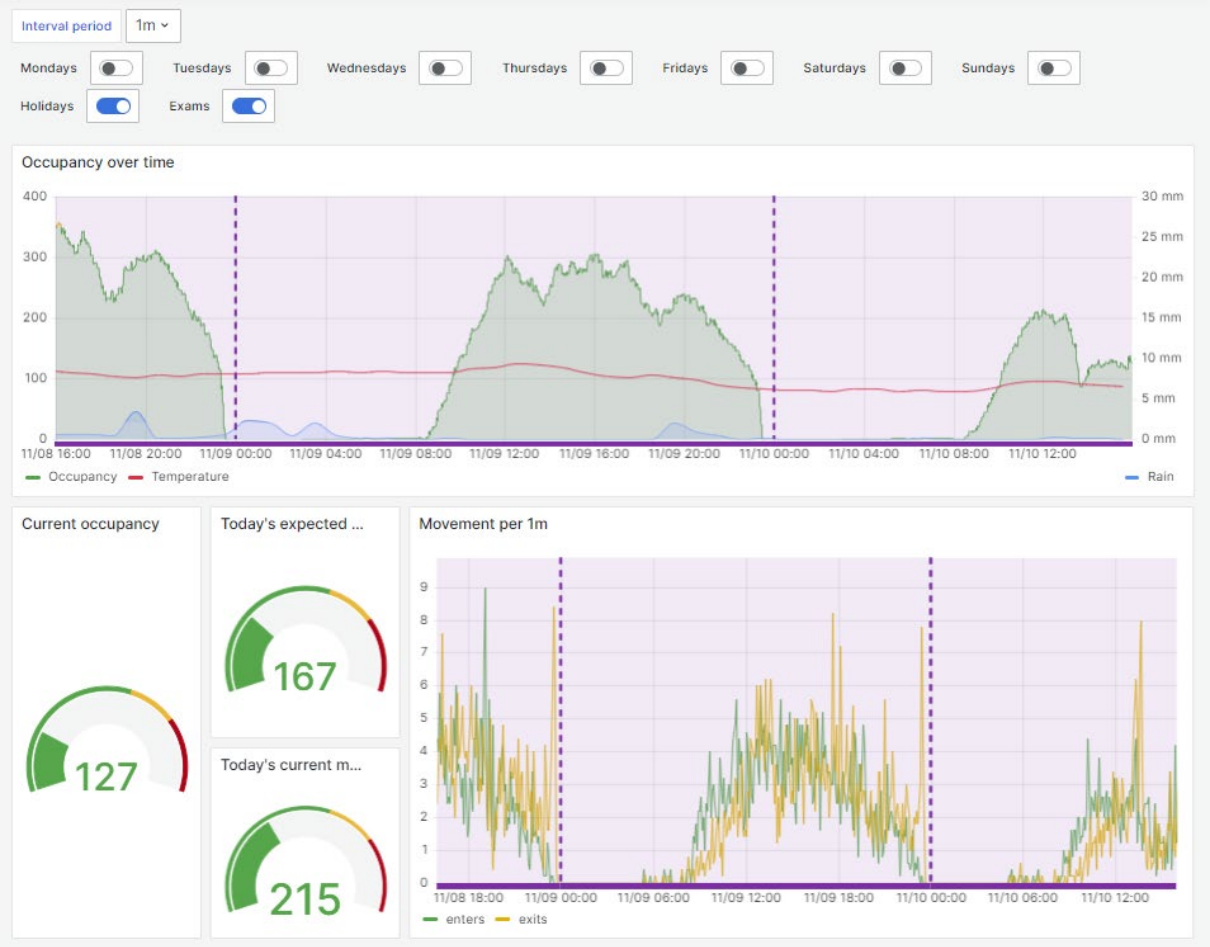

Figure 1. Grafana dashboard with UT library occupancy data visualisations created by TCS students, showing occupancy patterns, real-time occupancy data, and the expected occupancy.

Next to providing information about the real-time occupancy data, this dashboard allows users to gain insights on library occupancy patterns and provides predictions. However, this dashboard has not been made publicly available as of now. Therefore, there remains an opportunity and challenge to explore and identify the requirements and possibilities of a system that communicates this library occupancy data effectively to students in real-time.

An important thing to mention is that the data that will be used by the occupancy communication system is provided by the library through a database that stores the collected data from the sensors installed around the library. Consequently, even if the communication method could be effective in its data presentation, the actual occupancy could potentially be different. Therefore, the 'effectiveness' of the system only entails the ability of the system to present certain occupancy information.

Traditionally, data has been communicated in a digital manner, through mobile applications, web sites, etc. On the contrary, this project aims to explore innovative ways of utilising university spaces or everyday environments as interfaces to communicate the library occupancy information through a physical medium, known as a data physicalization [11]. Hence, an additional challenge and objective are to inform the design space for data physicalizations of library occupancy data at the university of Twente. In this context, the term 'design space' refers to the range of possible dimensions within which

the design of a product can be conceptualised and realised. It serves as a valuable element in product development and creation, offering a structured framework to comprehensively explore and integrate user perspectives, requirements, and potential functionalities specific to the context. Designers can use the design space to effectively understand the possibilities inherent in the product, which leads to creations of products that are both user-centric and contextually relevant.

1.3 Research questions

By looking at the above-mentioned challenges, the following research questions (RQ) and sub questions can be formulated:

- RQ1: How can a system be designed to communicate real-time library occupancy information to students?
    - RQ1.1: What occupancy information do the students need?
    - RQ1.2: When do they need the occupancy information?
    - RQ1.3: Where do they need the occupancy information?
    - RQ1.4: Why do they need the occupancy information?
    - RQ1.5: Who needs what occupancy information?
    - RQ1.6: How would they want the information about library occupancy to be physically communicated?

1.4 Report outline

This research report aims to give a comprehensive overview of the design and development process of the physicalization of the UT library occupancy data. Chapter 2 explores background and state-of-the-art research, providing context and laying a foundation for the ideation phase. Afterwards, Chapter 3 is concerned with the methods and techniques used to answer the research questions. Chapter 4 outlines the initial research findings, addressing the requirements for a system that communicates library occupancy at the UT, covering RQ1.1 to RQ1.5. In Chapter 5, the results of the exploration of design possibilities for representing occupancy data physically are presented and a design space for these physicalizations is defined, responding to RQ1.6. This is followed by an in-depth overview of the specification and blueprint for the realisation of one data physicalization in Chapter 6. Chapter 7 presents the insights and a reflective analysis of the physicalization design space and the participatory design workshop method. The overall research project and its limitations is then discussed in Chapter 8. Finally, Chapter 9 serves as the conclusion of the report, presenting answers to the questions researched in this project and their implications, and offers suggestions for potential directions for future work.

2 Background research

This chapter presents the background research conducted for this research project, focusing on occupancy monitoring systems, the state-of-the-art of existing methods for presenting building data, and relevant data physicalization case studies. The goal is to explore and review existing knowledge on these technologies, applications, and their implementations. This review will inform the design and development of an occupancy monitoring system and a data physicalization of this building data for the library at the University of Twente.

2.1 Literature review on occupancy monitoring systems

This literature review aims to provide a comprehensive overview of existing implementations of occupancy monitoring systems in various building environments, with a particular focus on university campuses. It will explore the diverse methodologies and technologies used in these systems, assess their effectiveness, and identify their limitations and challenges. Finally, the review will conclude with providing recommendations for the implementation of occupancy monitoring systems at the University of Twente library, along with suggestions for future research directions.

2.1.1 Overview of occupancy monitoring systems

From the research, it appears that a diverse and large variety of approaches have been explored to determine the number of people in a given space. These occupancy monitoring systems differ in their counting methodologies, utilising different hardware and software components to analyse and evaluate the number of occupants in a specific area. Occupancy monitoring systems are primarily categorised into two types: device-free and device-based methods [12]. Device-based methods require the occupant to carry a specific device whereas device-free methods operate without this necessity. In this review, solely a few occupancy methods will be discussed, as there are many technologies that could be used to count people.

One method of people counting, especially in public areas, is through utilisation of image and video analysis. Over a decade ago, Hou and Pang [13] made notable contributions to this field by developing a method that can effectively estimate the number and locate every individual in a low-resolution image. With only a 10% average error, their approach demonstrated considerable accuracy in people counting. With the technological advancements and progress, particularly in camera resolution and detection algorithms, research has shifted to people counting methods in more challenging scenarios. Zhou et al. [14] proposed a neural network for generating high-quality crowd density maps in challenging situations. Even though image and video analysis for people counting is often highly accurate, it requires significant amounts of data processing, raises privacy concerns, and has limited applicability for indoor spaces.

A non-image-based method for person counting utilises radio frequency-based solutions, integrating radio nodes in the monitored environment. Xu et al. [15] developed an algorithm that can locate and count individuals in a standard indoor environment with an average accuracy of 86%. Though, this method requires the installation of over 20 hardware devices and faces scalability challenges. As an alternative, Depatla et al. [16] proposed a system using a single stationary transmitter and receiver, coupled with a directional antenna. When used in indoor environments, it estimated the number of people with a margin of error of two persons or less in only 63% of the cases. However, the additional hardware installation of directional antennas presents a number of practical limitations.

While the requirement for hardware installation might be a practical limitation in occupancy monitoring, sensor-based approaches offer the possibility of a non-intrusive way to track occupants. There is a large number of sensors that could be used for collecting occupancy information, such as light-emitting diode sensors, acoustic sensors, carbon dioxide sensors, passive infrared sensors, and light detection sensors [12]. Moreover, systems are also not limited to a single sensor type and can incorporate hybrid solutions, offering a more accurate estimation of occupancy. Kouyoumdjieva et al. [12] notes that even though various sensor-based solutions are being proposed over time, none have advanced over others as most offer similar accuracy at comparable installation costs. However, these solutions are typically more suitable for environments with fewer occupants where moderate accuracy is acceptable.

Due to the presence of Wi-Fi access points in various settings coupled with the widespread use of portable devices with internet connectivity, new possibilities for using Wi-Fi in occupancy monitoring have emerged [12]. The system developed by Balaji et al. [17] had an 86% accuracy of localising occupants in a five-story building. Similar results were found by Melfi et al. [18] that deployed their Wi-Fi based approach in a university campus and reached 90% accuracy in their occupancy estimations. Although the systems seem promising and do not need additional instalments of sensors, precise localization of occupants remains limited to the number of access points [12].

Regarding occupancy monitoring practices at universities, particularly in university libraries, there are a few methods discussed in the literature. For example, Ju et al. [19] showed an approach using seat reservation data to assess occupancy patterns in university libraries. This allowed them to develop a low-cost and non-intrusive solution for occupancy monitoring, offering insights for post-occupancy evaluation that could inform the library in their decision-making process. However, its reliance on a reservation system may limit its applicability to other university spaces and its accuracy in detecting actual occupancy is questioned, as it may not account for non-reserved seat usage or the presence of individuals in other library areas. In contrast, Mohottige and Moors [20] focused on estimating room occupancy in a university campus using Wi-Fi sensors. Their method nearly matched the accuracy obtained by special-purpose sensors, as the system was able to predict the actual room occupancy in rooms with hundreds of occupants with an accuracy of 84%. This represents a significant advancement in occupancy monitoring, demonstrating the potential of Wi-Fi sensors in large-scale, dynamic environments like universities. However, Sutjarittham et al. [21] highlights that the use of Wi-Fi data for occupancy monitoring is not without privacy concerns. They propose a system of IoT sensors implemented in classrooms to monitor the real-time occupancy and artificial intelligence (AI) for predicting classroom usage. Even though this type of monitoring system is significantly more accurate, it is also more costly as compared to the other methods.

In conclusion, the choice of an occupancy monitoring method largely depends on the integration possibilities of hardware and software, the feasibility of hosting device-based or device-free systems, the intended purpose, and the desired level of accuracy. These factors must be carefully weighed when selecting an appropriate occupancy monitoring solution.

2.1.2 Utilisation of building occupancy data

The implementation of occupancy monitoring systems serves various purposes, informing building management about the human-building behaviour. The Wi-Fi-based monitoring system by Mohottige and Moors [20], is used to collect and estimate real-time room occupancy data in university buildings. This system not only gathers data but also classifies and analyses it to predict room occupancy. These predictions are used to dynamically allocate rooms for courses, with the goal to optimise building space usage at the university. Similarly, Sutjarittham et al. [21] developed a system offering recommendations

for optimal classroom utilisation in universities. Their approach differs from Mohottige and Moors in that they employed IoT sensors in classrooms for real-time occupancy measurement. Additionally, Ju et al. [19] focused on analysing library occupancy data to inform the design, operation, and management of university libraries. As the library environment is largely overlooked in existing studies, the in-building variety of places and the freedom of occupants to select seats, provides a unique opportunity to explore the human-building interaction.

2.1.3 Conclusion and discussion

The primary objective of this literature review was to examine existing implementations of occupancy monitoring systems, particularly focusing on university campuses like the University of Twente. The findings show a variety of methods in occupancy monitoring, ranging from device-based to device-free approaches. While accurate, systems utilising image and video analysis are constrained by privacy concerns and are less applicable to indoor environments. Although they are less intrusive, radio frequency-based solutions and sensor-based methods meet challenges related to installation and scalability limitations.

A significant finding is the potential of Wi-Fi-based systems, as shown by the research of Balaji et al. [17] and Melfi et al. [18], in providing accurate occupancy monitoring without the need for any hardware installation. However, these systems face limitations in precise occupant localization and raise concerns over privacy. A combination of occupancy monitoring methods, such as a combination of sensor implementation, Wi-Fi monitoring, and an occupancy data analysis method similar to the one proposed by Ju et al. [19] could be of value for the library at the University of Twente. However, the broad scope of technologies and the variety of applications as well as the absence of a clear framework to evaluate and compare different systems poses a key limitation of this literature research and complicates the ability to make definitive recommendations.

Future research should focus on developing a clear framework for evaluating occupancy monitoring systems that includes accuracy, cost, privacy, and ease of deployment. Exploring the integration of AI and machine learning could offer more precise predictive models, improving the system's accuracy and efficiency. Additionally, long-term studies that assess the impact of these systems in real-world settings would also contribute valuable insights into their effectiveness.

2.2 State-of-the-art

2.2.1 Situated visualisations

To communicate occupancy data, a common method involves the use of situated visualisations [22]. These visual graphics are displayed in the related environment to communicate the occupancy information to users. For instance, restroom occupancy indicators on aeroplanes and trains allow travellers to check availability without leaving their seats (see Figure 2a), and parking lots use digital counters at strategic locations to guide individuals to vacant spots more efficiently (see Figure 2b). Certain train operators and stations display real-time occupancy information for train compartments both on platform screens (see Figure 2c) and within the trains themselves (see Figure 2d), enabling passengers to choose less crowded areas.

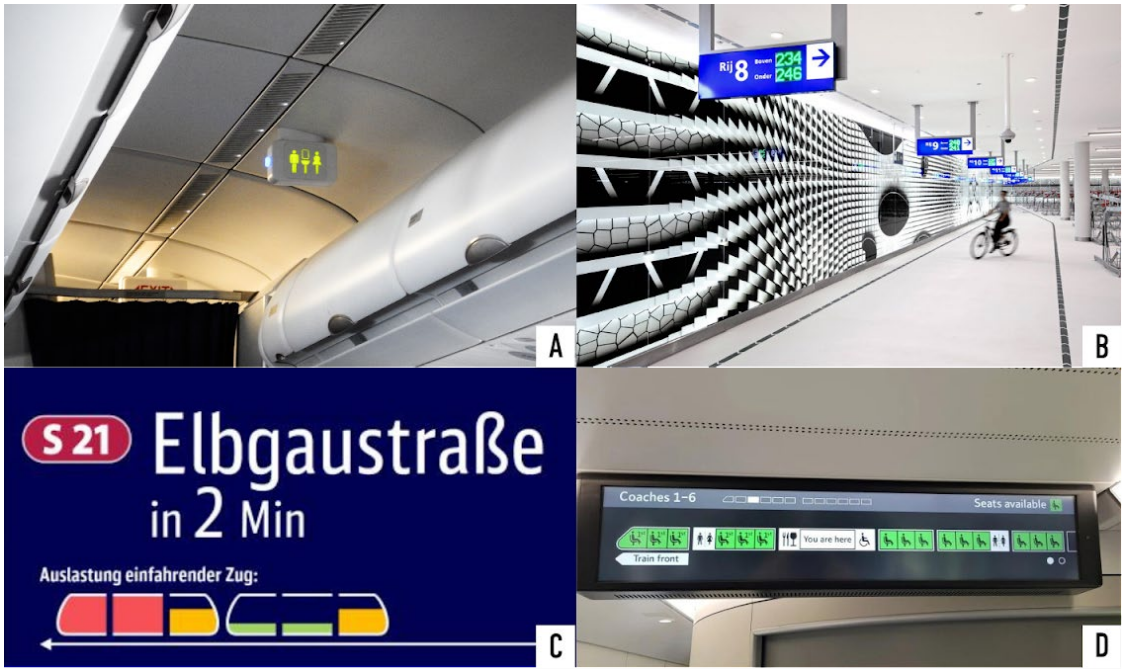

Figure 2. Examples of situated visualisations of occupancy data: (A) restroom occupancy indicator in an aeroplane, (B) occupancy counter displays in the underground bicycle garage at the central station in the Hague, copyright: Mike Bink [23], (C) the occupancy information presented on display boards at train stations in Germany, the board shows in red, yellow and green how full the individual wagons are, credit: DB AG [24], (D) the on board displays of the Greater Anglia Intercity show with colour indications where seats are available on the train [25].

During the Covid-19 pandemic, digital signage emerged as a low-cost, effective method for displaying real-time occupancy levels. These signs, which were often used by supermarkets and retail stores, provided updates on the number of people inside a building, informing visitors about the current occupancy and indicating whether it was safe to enter based on capacity limits and the guidelines for social distancing (see Figure 3).

Figure 3. Examples of situated visualisations of occupancy data with digital signage: (A) diagram of Irisys SafeCount live occupancy monitoring system with visual warnings and alerts when limits are approached or exceeded [26], (B) Dilax live occupancy monitoring display showing the maximum store capacity, free capacity, and an alert indicating that it is safe to enter the building [27].

Digital signage is not solely used for sharing occupancy counts, it also enables spaces to provide more comprehensive information to users within various spaces like offices. Unlike systems that display current occupancy levels, advanced applications integrate detailed indoor maps, enhancing the information provided with details about occupancy at specific areas within a building. Companies like

Freespace offer smart sensor systems paired with digital signage [28]. Next to visualising occupancy data, this technology also incorporates touchscreen wayfinding features to empower users not only with real-time occupancy information, but with the ability to select and navigate to particular spots within the building (see Figure 4).

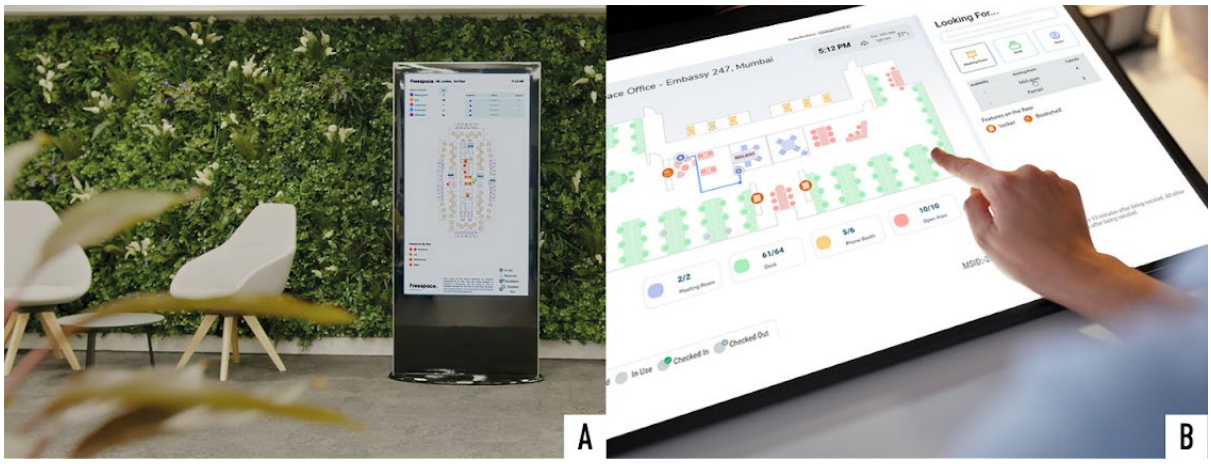

Figure 4. Freespace occupancy data sharing method with digital signage solutions for offices: (A) an example of digital signage in an office workspace [28], (B) a detailed view of the interactive indoor office map, where a user engages with the live touchscreen for the wayfinding feature [28].

2.2.2 Mobile applications

In addition to situated visualisations, mobile applications serve as another platform for communicating occupancy information, enabling users to access data through devices like smartphones or laptops. For instance, the NS app [29] is used by the Dutch Railway system, which not only facilitates trip planning but also displays real-time train occupancy rates as percentages (see Figure 5a). Moreover, the app incorporates a feedback mechanism that allows passengers to contribute occupancy data by describing the conditions inside the train (see Figure 5b). As a result, the NS app functions both as a communication tool for sharing occupancy data and a platform for data collection from its passengers.

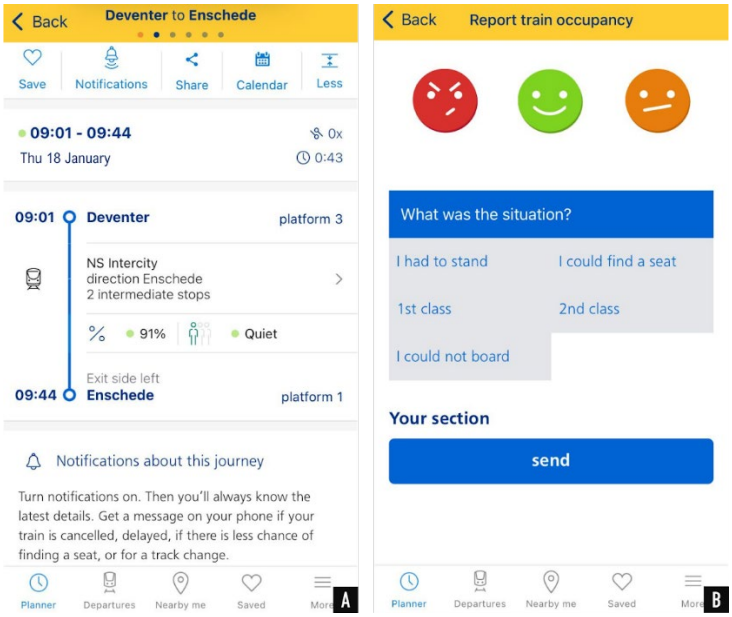

Figure 5. The NS application functionalities: (A) shows a train journey with a 91% occupancy indication, signifying a quiet train environment, (B) displays the user feedback menu, which offers various options for passengers to report on train occupancy levels.

In office environments, applications are also frequently used to communicate real-time indoor occupancy and provide analysis outcomes to indicate space utilisation, particularly in areas like meeting rooms. This information enables companies to refine their space management strategies and tailor services, such as cleaning schedules, and with this enhance their efficiency and overall workplace environment. In these applications, the real-time indoor occupancy is often shown in the form of heat-maps as can be seen in Figure 6.

Figure 6. Examples of apps that indicate building occupancy on digital maps: (A) displays the infsoft Workplace Experience app showing current room utilisation in a 3D map [30], (B) demonstrates office occupancy heat map example of the CoWorkr software on a desktop [31], (C) shows other instance of an office occupancy heat map of the CoWorkr software [31].

Not only companies, but also academic research projects often make use of mobile applications to show indoor occupancy data to users. For instance, Ju et al. [19] uses a digital reservation system for its indoor occupancy sensing, but it is also directly used to show the real-time occupancy to users. Similarly, Rudin et al. [32] created an IoT system for monitoring the occupancy of sports facilities at a university campus. They created a mobile application where students not only can book a specific facility, but also can see the real-time and scheduled occupancy. These examples demonstrate the diverse applications of web interfaces in occupancy monitoring, showing that the versatility of this technology can facilitate features that go beyond solely presenting occupancy data, but can integrate many features to further enrich or enhance the user experience.

2.2.3 Data physicalizations

While traditional data visualisations are typically presented on separate screens or displays, data physicalizations are representations of data that are integrated with physical objects, spaces, or entities [33]. This allows for interaction with the data in its original context, which could facilitate more intuitive analysis of the data and could allow for better understanding of the data. Physicalizations offer data to be perceived not only visually, enabling users to experience the data haptically, aurally, or even through taste. By utilising diverse modalities and encoding channels, such as light hue, vibration duration, or

sound pitch, physicalizations of data offer a more versatile and diverse communication method. There are many examples of data physicalizations for a variety of applications, however in this section examples of data physicalization that are specifically relevant in the context of real-time building data communication systems will be discussed.

One example is CairnFORM [34], which is a desk-sized, shape-changing ring chart that is designed to display energy availability in public spaces. The main goal of CairnFORM is to create an object that can assist individuals in creating new energy consumption practices, by showing this data in a pleasant and appealing order. Its cylindrical form enables users to see the information from any angle, as shown in Figure 7. Each ring corresponds to an hour of the working day, with illuminated rings to indicate hours that have already passed during the day, while the expansion or contraction of the rings conveys the energy availability data. The researchers specifically chose to integrate shape-changing cues, as it is perceived better than light-changing stimuli [35].

Figure 7. The CairnFORM prototype [34], displaying variations of different sizes during a public event. Left image shows the physicalization at 12 hours, the centre image at 13 hours, and the right image at 17 hours.

The Tidal Memory [36] data physicalization represents the daily tide cycle in the San Fransisco Bay area. It entails a number of glass columns filled with water that act as a visual clock system, presenting hourly tide levels throughout the day using live data (see Figure 8a). With each passing hour, the water in a new column rises to reflect the current tide height, remaining at that level until the start of the next day, providing visitors with a direct, clear view of the tide levels throughout the day.

Another data physicalization using water in pipes to present data was Van der Veen's graduation project at the University of Twente, which utilised water-filled pipes to present water usage within campus buildings [37]. Named the HydroSumption, this installation features an individual pipe for each campus building with an interface allowing users to select a specific month for the data representation (see Figure 8b). Corresponding to the water consumption in a selected month, the water in the pipe will rise to a specific height for each building. While this installation displays building data, it operates on a predetermined dataset rather than real-time information.

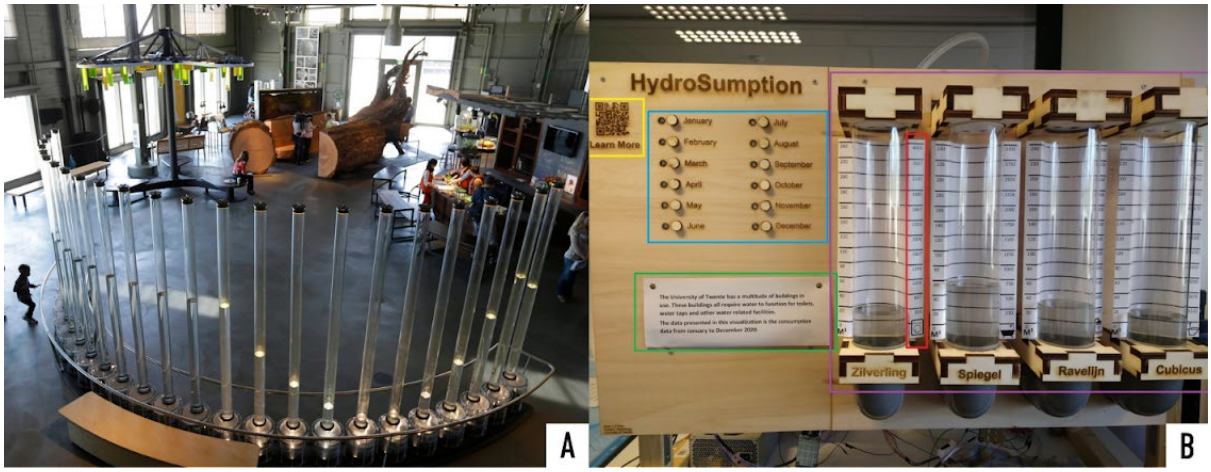

Figure 8. Examples of data physicalizations using water-filled pipes to present data: (a) The Tidal Memory [36] installation displaying the height of the tide in the San Francisco Bay area for each hour of the day, (b) front view of the HydroSumption [37] installation with the user interface on the left side with buttons for each month and the pipes filled with water for each building on the right side.

An example of a data physicalization that integrates data sensing and presentation within the same space is the Wavefunction installation [38]. This work consists of four rows of chairs placed in a room equipped with occupancy sensors and dynamically responds to visitors passing by (see Figure 9). Upon detecting a visitor's approach to the installation, the closest chair elevates, triggering a chain reaction among the other chairs, resulting in a simulation of the propagation of a wave. This example demonstrates the immediate translation of sensed data into real-time interactive experiences.

Figure 9. Wavefunction installation [38]: (a) shows the installation from above showing the four rows of chairs, (b) demonstrates the installation from the side with some elevated chairs, (c) displays the camera view and application that is used to sense the passersby and actuate the elevating chairs.

Other data physicalizations presenting real-time data include LOOP [39] and Laina [40], both designed for home environments and utilising activity data collected via smart sensors. While both physicalizations translate users' activity data, they differ in their methods and outcomes. LOOP visually represents activity levels by changing the shape of a desk-sized object, including a ring for each day of the week with one ring serving as the activity goal (see Figure 10a). The rings move closer to the goal based on daily activity levels, which offers users an immediate overview of their weekly activity. In contrast, Laina transforms running data into a shape-changing artwork, where pins extend more in areas where the user has run faster (see Figure 10b). The change of the shape does not happen instantly but slowly over time and allows users to push back the pins before their next run. By allowing users to manipulate the physicalization, their experience with the data is enhanced by fostering a more engaging interaction.

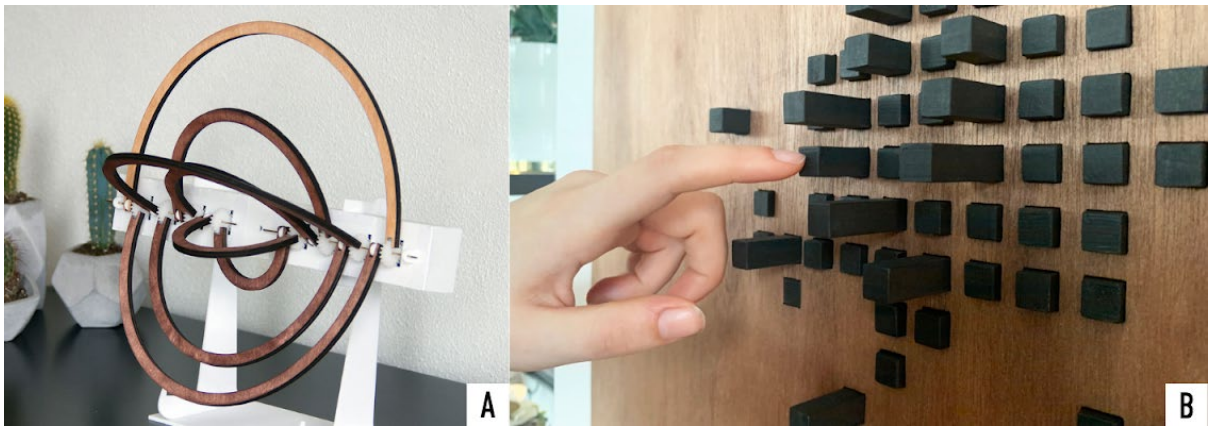

Figure 10. Data physicalizations that translate real-time data: (a) demonstrates the LOOP artefact [39], featuring an outer ring representing the activity goal and seven inner rings arranged at different angles relative to the outer circle, (b) shows a user interacting with the Lain data physicalization artwork [40] by pressing one of its pins.

To the best of our current knowledge, there is no known data physicalization method designed explicitly to communicate real-time library occupancy. However, the examples provided in this section demonstrate the diverse approaches and possibilities for translating and presenting building or real-time data using physicalizations techniques. Unlike traditional (situated) data visualisations, data physicalizations offer a unique approach by integrating data directly into the physical environment. This closer proximity between the data presentation and the data referent may pose a significant opportunity for making building data more accessible and engaging.

2.3 Conclusion

In conclusion, this chapter reviewed literature and projects to explore existing occupancy monitoring systems, existing methods for presenting building data, and relevant data physicalization case studies. The goal of this review was to gather insights that could inform the design and development of an occupancy monitoring system and corresponding data physicalization for the UT library.

The literature review on occupancy monitoring systems demonstrates a wide variety of sensing methods currently being explored, each with its own set of advantages and limitations. Although some methods show promising levels of accuracy, concerns regarding the privacy of indoor occupants while using these methods complicate their ethical application. Nevertheless, there is a trend towards the development and use of sensors that do not compromise personal privacy while offering increasingly accurate occupancy monitoring, which show potential for integration in an expanded occupancy monitoring system at the library.

The state-of-the-art review presents methods for real-time occupancy data communication, showing the common use of situated visualisations and mobile applications as the primary technique. Situated visualisations provide real-time updates on occupancy levels within specific environments, while mobile applications offer users flexibility in accessing data from any location and often include additional service features. While these communication methods may work effectively in communicating library occupancy, data physicalizations offer an alternative approach to present this data. Examples such as CairnFORM [34], Tidal Memory [36], and Wavefunction [38] demonstrate the potential of data physicalizations in creating engaging and immersive experiences for users. Moreover, by integrating data physicalizations into their environment, the accessibility and interactivity of the building data may be enhanced.

Overall, the background research showed the variety of opportunities for sensing and presenting occupancy data in an indoor environment. While traditional methods seem to be effective, exploring alternative approaches to communicating data, such as with data physicalizations, seem to have potential to further enhance the communication of occupancy data in the context of the UT library.

3 Methods and techniques

The main two objectives of this research project are to find the requirements for a method to communicate occupancy data of the library at the University of Twente and to explore the design space of (possible) data physicalizations in this context. The overall setup of the research, therefore, was twofold. The first part focused on addressing the first five sub questions (RQ1.1-1.5), utilising both quantitative and qualitative methods to identify the requirements for a method to convey library data to the students. The second part, focused on answering sub question RQ 1.6, made use of a participatory design approach to explore the possibilities to convey the library occupancy data in a physical manner and involved a qualitative data analysis to define the design space for these physicalizations. Additionally, one of the data physicalization ideas will be developed further and specified to demonstrate how this system could be created.

3.1 Identifying system requirements

The data acquisition methods for addressing the first five sub research questions (RQ1.1-1.5) involved both a quantitative and a qualitative approach. First, a survey was conducted among library users to gather insights from a large group of potential users. The main objective and focus of this questionnaire were to understand the factors influencing decisions of library users when choosing the library as a study location. In addition to these insights, the survey included questions regarding their library usage and perceptions of specific occupancy data, aiming to gather insights for the specific data needs. The results from the survey were analysed with simple statistics to interpret the findings.

Additionally, to obtain more detailed and in-depth insights into the decision-making processes of students regarding their choice of study location, focus group sessions were conducted. In each session, participants were also asked to complete a short questionnaire for the assessment of various types of library occupancy data using a Likert scale. The data collected from the focus group sessions were analysed using thematic analysis to identify emerging themes and patterns. The results from the Likert scale questionnaire were analysed with descriptive statistics to further interpret the findings.

3.1.1 Survey

Surveys are commonly used to identify user behaviour and specify their needs [41]. Therefore, a survey was designed to gather insights from a broad spectrum of library users at the University of Twente, aiming to explore the factors influencing their choice of the library as their study location. The survey was composed of multiple-choice questions as this allowed for easy data interpretation and identification of patterns. Additionally, the length of the survey was kept short to respect the time constraints of students studying at the library. The survey was created digitally using Google Forms and communicated to the students with QR-code links. The responses were analysed with Google Sheets, using statistical metrics like percentages and correlations to interpret the data.

3.1.2 Focus group

Although analysis of the results can be complicated, focus groups can be a useful method to understand a range of perspectives as it involves multiple participants in a discussion about a certain topic [42]. Therefore, focus groups were held to obtain a deeper understanding about the decision-making process when selecting a study location among students. Each session included a diverse group of students to ensure that a variety of perspectives and insights were represented. The discussions were hosted by the main researcher and were semi-structured, guided by a set of predetermined, open-ended questions that encouraged participants to share about their habits, experiences, preferences, and suggestions regarding

library usages, study places, and occupancy data. The sessions were audio recorded and transcribed for thematic analysis to extract common themes and patterns in the responses [43].

3.1.3 Likert scale questionnaire

A short questionnaire with a modified version of a Likert scale was distributed among the focus group participants to investigate their views on the utility of various occupancy data types in a quantified manner. Likert scales involve closed-ended questions with an ordered response, often asking users where they fall on a scale from 1 to 5 for a given statement [41]. The scale in the used questionnaire ranged from 1 ‘not useful’ to 5 ‘very useful.’ The analysis of these responses involved computing the average scores per data type and examining the distribution trends in order to extract an interpretation of the views on the utility of the suggested occupancy data types.

3.2 Exploring the design space

This phase of the research project was specifically focused on exploring and defining the design space for physicalizations of library occupancy data. The study took a user-centred approach in exploring the scope of data physicalization opportunities by involving the main user group in participatory design workshops. The design ideas generated in these workshops were then analysed and used in combination with information from established data physicalization design spaces to define the library occupancy data physicalization design space.

3.2.1 Participatory design workshop

Participatory design, a method commonly used in user-centred design, emphasises the collaboration between users and designers to ensure that the products or services resonate with user needs and preferences [44]. This approach not only involves users to gather their valuable insights but also empowers them by making them active contributors to the design process. In this research project, the participatory design workshop was structured to create an environment fostering creative collaboration and engagement among participants to generate a variety of data physicalization designs for library occupancy.

Inspired by the co-creation procedure used to explore health data representations among elderly [45], the workshops were structured into four phases: the introduction, icebreaker, the main design, and a presentation and discussion:

- *Introduction phase*: The researcher presents the main objectives of the workshop to ensure the participants understand the context of the project and the task at hand. In this project, a presentation was provided about the research, data physicalization concepts, and an overview of the design activities.
- *Ice breaker phase*: Participants are invited to partake in an activity to acquaint themselves with one another and to establish a collaborative momentum for idea exchange. In this project, a focus group served as the icebreaker, enabling participants to express their ideas and discuss topics relevant to the design session.
- *Main design phase*: Participants are divided into groups to collaboratively engage in the creative process of designing a specific object or service. For this project, this phase involved the ideation and creation of a low-fidelity prototype for data physicalization using various physical design materials.

- *Presentation and discussion phase*: Each group presents their ideas and concept to the rest of the participants, followed by a group wide discussion to gather opinions and insights for further evaluation of the design concepts.

Normally, the design process has an iterative nature, involving the repetition of certain phases to polish and refine the design concepts. However, due to the constraints of this research project, there was one main design session involved for each workshop and the ideas resulting from this workshop were then used for further analysis.

3.2.2 Categorization method

To inform the design space for physicalizations of library occupancy data, a mixed method approach was employed integrating the structural coding method as described by [46] with reflexive thematic analysis as outlined by [47]. A similar process for the qualitative data analysis as shown by [48] was used to extract the dimensions for the design space. This method facilitated a structured, yet flexible analysis of the data gathered from the participatory design workshop, allowing for an exploration of both pre-existing and emergent dimensions for data physicalizations.

Initially, the researcher carefully analysed each proposed data physicalization idea to gain a comprehensive understanding of the diversity and depth of the concepts presented. This was followed by a systematic identification of initial codes, which entailed tagging specific aspects within the data that appeared interesting or relevant in the context of data physicalization dimensions. Afterwards, the different codes were examined to identify broader patterns of meaning and potential dimensions. These initial dimensions were reviewed and checked if they were applicable across the entire collection of data physicalization ideas. Then, this set of initial dimensions was compared with established dimensions from existing literature to refine and merge them and to incorporate additional relevant dimensions that had not emerged in the preliminary analysis. Finally, the collection of dimensions along with their options was clearly defined and described.

3.3 Refining data physicalization concept

In this phase of the research project, one of the data physicalization concepts that emerged from the participatory design workshop will be further refined. The creative technology design process as outlined by Mader and Eggink [49] describe how the development of a system typically involves an iterative process of four phases: ideation, specification, realisation, and evaluation.

The ideation phase involves the generation of multiple design concepts through brainstorming. In the case of this research project, the ideation phase will mainly take place during the participatory design workshops after which one specific idea is selected by the main researcher and the project supervisor. This selection was guided by the envisioned future design scope of the data physicalization concept. The aim of refining the idea further was to serve as a demonstration and a source of inspiration for other researchers and designers. Specifically, the goal was to showcase the potential of integrating physicalization techniques into real-world contexts. Moreover, the refined system aimed to illustrate how building development could adopt a data-centric approach to empower building occupants by making data more accessible.

The specification of the system typically involves iterative prototyping to refine the design according to system requirements. However, in this research project, physical prototypes were not developed due to the scope and time constraints of the research project. Instead, insights from the initial brainstorming phase and feedback from the first phase of the research project regarding the system

requirements will inform specification of the system in terms of functional and non-functional requirements [50] and are prioritised with the MoSCoW method [51].

The last two phases of the creative technology design process involve the realisation and evaluation of the final system by translating the specifications into actual system components and performing user tests. However, in this project, these phases will be approached differently as the system will not be realised in practice, aligning with the scope of the research project. The realisation of the system will solely entail providing a detailed overview of the system components and interaction flow as if it were to be developed, offering a blueprint for actual implementation.

3.3.1 Requirements

The requirements of the system emerged from the description of the design as provided during the participatory design workshop and by analysing the user and stakeholder needs. These requirements were prioritised following the MoSCoW method [51] [52] and categorised as functional or non-functional requirements [50].

MoSCoW method

The MoSCoW method [51] [52] is a prioritisation technique used to organise requirements of a certain system that can assist designers and developers in identifying the essential and less critical needs for the realisation and implementation of a system. This method categorises each requirement into one of four groups:

- *Must have*: refers to essential requirements that create the foundation of a system.
- *Should have*: presents important requirements that are critical, but would enhance the functionality of the system.
- *Could have*: involves features that would be desirable but are of lower priority.
- *Will not have*: describes requirements that will not be included in the system (in the current development cycle) due to constraints such as the budget or scope of the project.

Functional and non-functional requirements

System requirements are typically categorised into two main types: functional and non-functional [50] Functional requirements focus on what the system does, such as the specific behaviours and functionalities it should perform. Non-functional requirements describe how the system performs these tasks, focusing more on its quality attributes. While functional requirements can be used to evaluate the functionality of the system, non-functional requirements can be used to assess the system on its usability and overall performance [53].

4 Survey and focus group results

This chapter includes a description of the setup and a presentation of the results of the survey and focus groups that were conducted among students at the University of Twente. The survey and focus groups were included in this research project to gather relevant information about the user group about their library usage and decision-making behaviour to inform the requirements of a system that communicates library occupancy data.

4.1 Survey

This section presents an overview of the survey conducted among students at the University of Twente. It first outlines the objectives of the survey, followed by a description of the study design and the participants involved in the study, and finally presents the survey results. Concluding remarks about these findings is presented in Section 4.3.

4.1.1 Objectives

The purpose of the survey was to gather insights into the decision-making process of university students in their library usage. The main objective was to collect data to answer the sub research questions related to the requirements of the occupancy data communication system outlined by RQ1.1 until RQ1.5:

- RQ1.1: What occupancy information do the students need?
- RQ1.2: When do they need the occupancy information?
- RQ1.3: Where do they need the occupancy information?
- RQ1.4: Why do they need the occupancy information?
- RQ1.5: Who needs what occupancy information?

4.1.2 Study design

The survey was conducted among students attending the library of the University of Twente. It was conducted over a month-long period, including the last week of the first module and the first three weeks of the second module of the academic year. This time period was deliberately chosen to capture varying levels of library occupancy, particularly during peak occupancy periods such as during exam weeks at the end of a module. Moreover, the in person, active recruitment of students was done on various days of the weeks, during various moments throughout the day, to ensure a diverse and representative sample of the student population was reached, reflecting the different study schedules.

Participation in the survey was actively promoted with a dual approach, including strategically placed flyers with QR codes within the library building to access the online questionnaire, with visuals presented on the large displays inside the library, and by actively recruiting students at the library entrance. The visuals used for the flyer and online promotion can be found in Appendix A.

The questionnaire included an information letter to provide participants with an outline of the purpose and scope of the survey, a consent form constructed with the ethical research standards as defined by the University of Twente, and the main questions. There were in total five main questions, with one question derived from each of the sub research questions. These questions were closed-ended, but the respondents were also able to provide their answers if they were not included in the suggested answers.

Furthermore, there was one question regarding demographics to capture specific participant characteristics entailing their major or field of study. This question was altered after the first few surveys

were conducted as it was somewhat unclear to the students what was asked. An overview of these questions and their answer options are shown in Table 1. The complete questionnaire, including the information letter and consent form, can be found in Appendix B.

Table 1. Overview of the questions and answer options of the library wide survey focusing on students' decision-making process and behaviour related to the library.

Nr.	*Question*	*Answer options*
Q1	When did you decide to study at the library today?	Multiple choice (select 1): 1. Spontaneously, right before going there 2. Spontaneously, before going to the campus 3. Spontaneously, during class 4. I planned it ahead, less than 2 days prior 5. I planned it ahead, more than 2 days prior 6. Someone else planned it (e.g. for a group session or working together) 7. Other…
Q2	Where were you when you made this decision?	Multiple choice (select 1): 1. At home 2. On campus Could you share where you were on campus? Were you in a lecture? (open question) 3. I don't remember 4. Other…
Q3	What is your primary purpose for being in the library?	Multiple choice (select 1): 1. Studying by myself 2. Studying with others 3. Meetings 4. Using the library resources 5. Other…
Q4	What specific information about library occupancy would be valuable to you?	Check the boxes that are relevant: 1. Today's visitors history 2. Same hour occupancy over the past 5 day 3. Number of free seats 4. Number of seats in use 5. Other…
Q5	How does library occupancy information impact your decision to visit or avoid the library?	Multiple choice (select 1): 1. To plan my library visits efficiently 2. To choose suitable times for group study 3. To select optimal study periods, especially for exams 4. To find vacant seats or study rooms easily 5. To check if the current library's atmosphere matches my study atmosphere preferences 6. To avoid overcrowded conditions 7. It wouldn't impact my decisions 8. Other…

4.1.3 Participants

The participants involved in the survey were all students at the University of Twente who were attending the library at the moment of participation. There were no exclusion criteria based on demographics, the only requirement for the students was that they were attending the library at the moment of participation in the survey.

4.1.4 Survey results

A total of 74 students participated in the survey. The results of the demographic question regarding the major or field of study of the participants showed a diverse representation across 20 different academic disciplines. The largest groups included students majoring in Technical Computer Science and Electrical Engineering, with ten and eight participants respectively. However, nine respondents did not provide a response to this demographic question due to its initial unclear formulation. Additionally, one participant reported a double major in Applied Mathematics and Technical Computer Science, both of which have been included in the list of majors. An overview of the distribution of participants per academic field can be found in Table 2.

Table 2: Distribution of participants per academic field

N	*Major*
10	Technical Computer Science
8	Electrical Engineering
6	Creative Technology
5	Mechanical Engineering
5	Applied Physics
4	Technical Medicine
3	Advanced Technology
3	Business Information Technology
3	International Business Administration
3	Industrial Design Engineering

N	*Major*
2	Educational Science and Technology
2	Civil Engineering
2	Communication Science
2	Industrial Engineering and Management
2	Applied Mathematics
2	Biomedical Engineering
1	Embedded Systems
1	Psychology
1	Robotics
1	Civil Engineering and Management

When the participants were asked about their decision-making process regarding their visit to the library, the majority (67.6%) indicated that they planned their visit ahead of time, with over half of them deciding this less than two days prior. Conversely, 28.4% students decided this spontaneously, with 16.2% deciding this before going to the library and 12.2% before going to campus (see Figure 11).

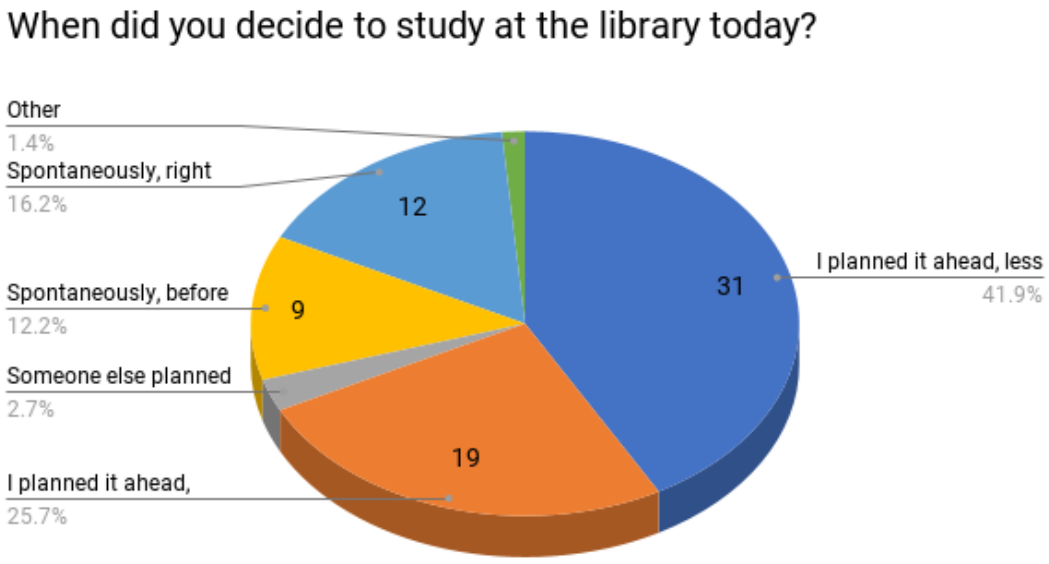

Figure 11. 3D pie chart showing the distribution of responses to the question "When did you decide to study at the library?" The chart displays both the actual number and relative percentage of responses across different categories. The exact response options can be found in Table 1.

A significant majority of the respondents, 63.5%, decided to go to the library when they were at home, while a quarter of the respondents, 25.7%, indicated that they were on campus when deciding to go to the library. A smaller group, 6.8% of the respondents, could not recall their location when making this decision, while 4.1% shared being in specific locations, such as public transportation, at the time of the decision-making process, as can be seen in Figure 12.

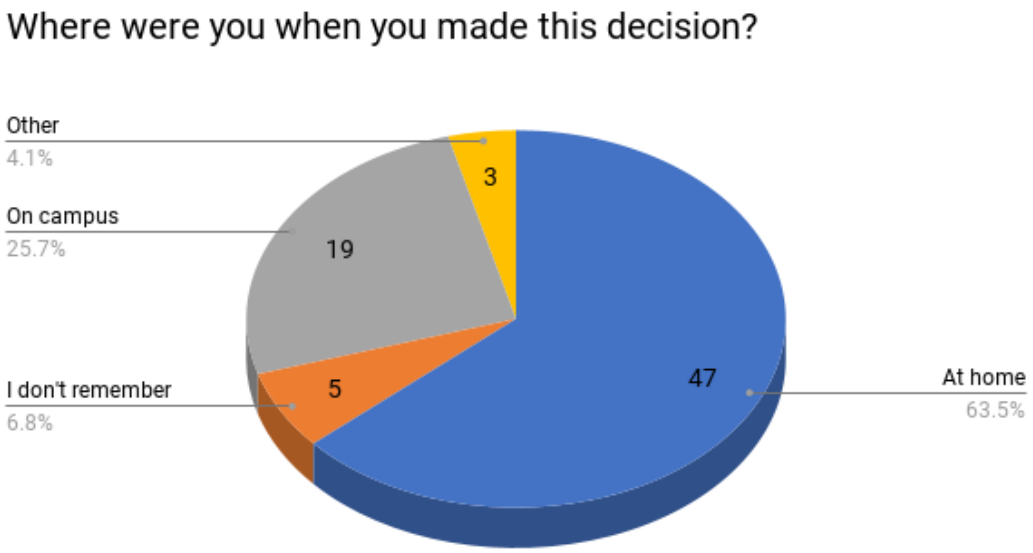

Figure 12. 3D pie chart showing the distribution of responses to the question "Where were you when you made this decision?" The chart displays both the actual number and relative percentage of responses across different categories.

Interestingly, when cross-referencing the responses from these initial two questions, it was revealed that 44.6% of those students who planned their library visit ahead were at home, contrasting with only 16.2% who were on campus (see Figure 13). Conversely, 16.2% of the respondents were at the university when they planned their library visit ahead, while 9.5% decided to go to the library spontaneously while already being on campus.

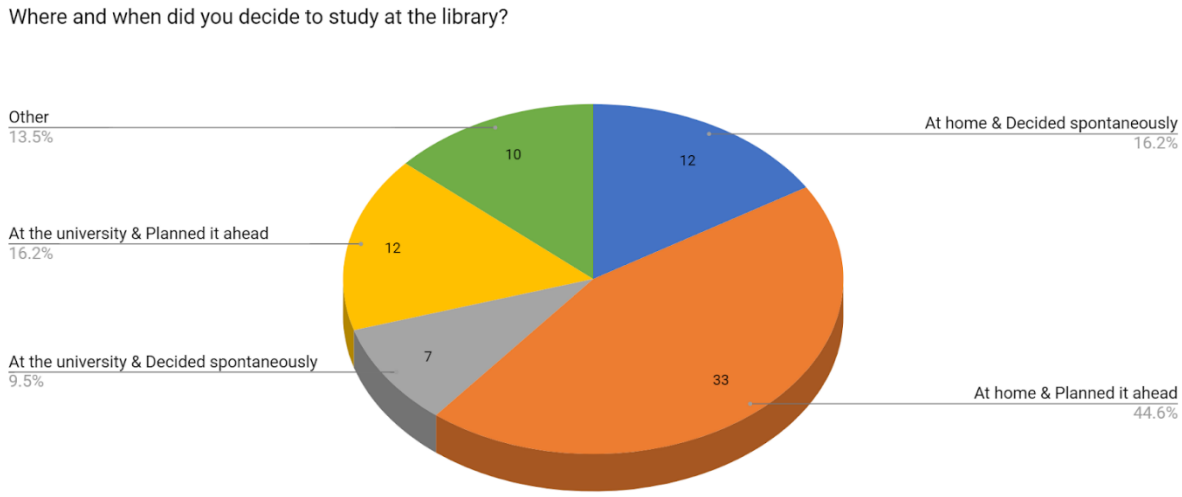

Figure 13. 3D pie chart showing the distribution of responses of the combined responses of the questions "When did you decide to study at the library?" and "Where were you when you made this decision?" The chart displays both the actual number and relative percentage of responses across different categories.

There was a relatively even split among students studying alone versus with others at the library, with 54,1% studying alone and 40,5% studying with others, which is shown in the chart from Figure 14.

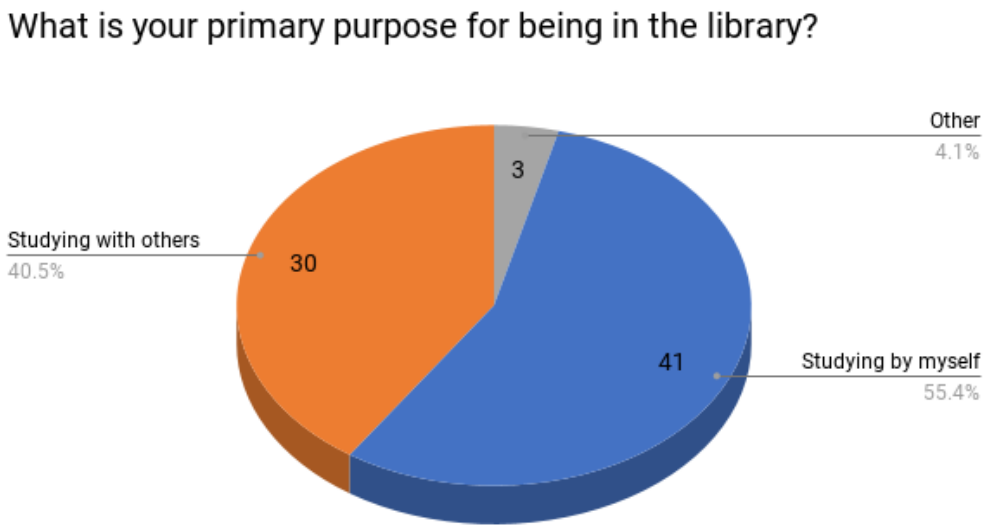

Figure 14. 3D pie chart showing the distribution of responses to the question "What is your primary purpose for being in the library?" The chart displays both the actual number and relative percentage of responses across different categories. The exact response options can be found in Table 2.

When asked about the specific types of information regarding library occupancy that students found valuable, all participants selected at least one option, with 64.9% choosing more than one data type (see Figure 15). The most chosen data type was the number of free seats, selected by 83.8% of respondents. Other data types were chosen by roughly half of the participants, including today's visitor history (56.8%), number of seats in use (52.7%), and same-hour occupancy over the past five days (47.3%). Students also suggested additional types of data, such as the number of seats available in the silent versus non-silent areas, weekly occupancy averages, availability and reservation status of project rooms, and availability of monitors, among others.

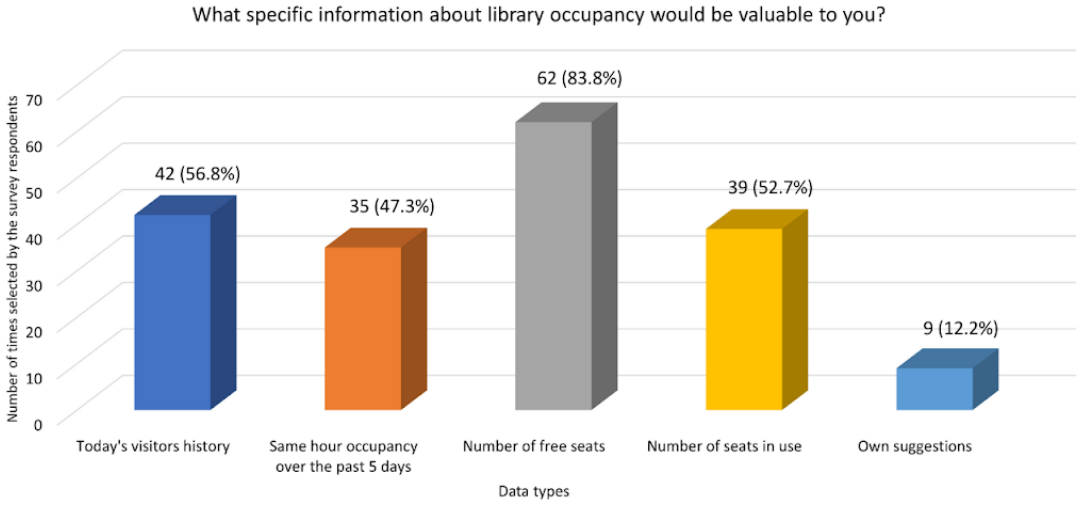

Figure 15. 3D column chart showing the distribution of responses to the question "What specific information about library occupancy would be valuable to you?" The chart displays both the actual number and relative percentage of responses across different categories.

Regarding the impact of library occupancy information on their decision-making process, only 9.5% of participants stated that it would not influence their decisions. The majority (28.4%) indicated that they would use the information to avoid overcrowded conditions in the library, while 21.6% mentioned using it to efficiently plan their library visits. Additionally, 20.3% of the participants indicated that they would use it while attending the library to easily find vacant seats or study rooms. A visualisation of these results is presented in Figure 16.

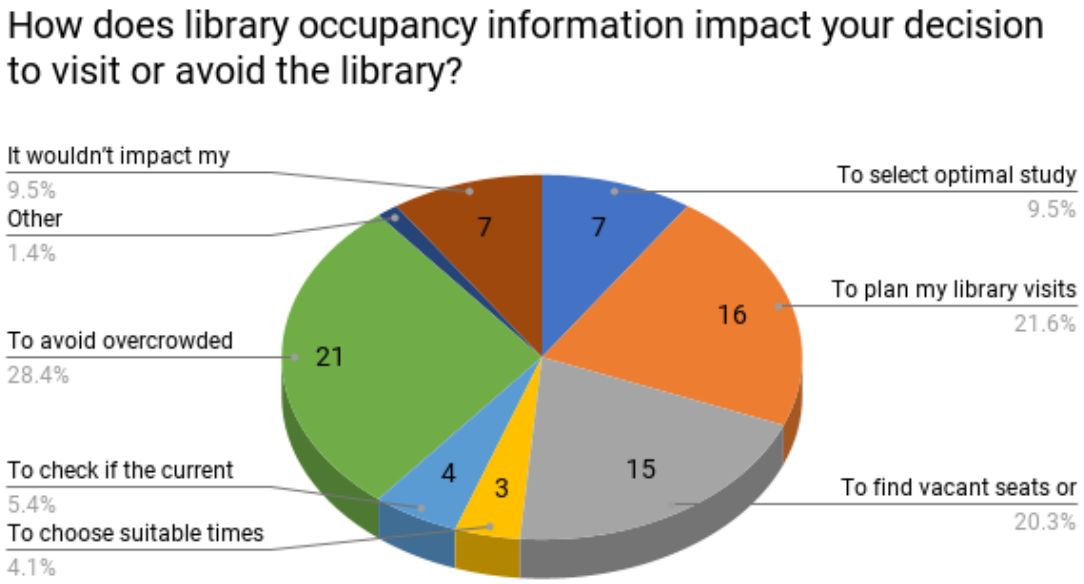

Figure 16. 3D pie chart showing the distribution of responses to the question "How does library occupancy information impact your decision to visit or avoid the library?" The chart displays both the actual number and relative percentage of responses across different categories. The exact response options can be found in Table 1.

4.2 Focus groups

In this section a description of the conducted focus groups is given that was held among students at the University of Twente regarding their decision-making process in choosing a study place. First, the objectives and the main goals of the focus groups are specified, after which the setup of the sessions and a description of the participants is given. The section concludes by presenting the results, which are further discussed in Section 4.3.

4.2.1 Objectives

The main objectives of the focus groups were to gather detailed insights from a variety of students regarding their decision-making process in choosing a study place, particularly around campus and the library. Moreover, the focus groups were used to gather feedback and opinions about certain occupancy data. This qualitative information is essential in determining the system requirements, as it provides deeper understanding of the main user group and their specific needs.

4.2.2 Study design

Three focus groups were held consecutively over the course of three days at the University of Twente. These sessions formed part of the participatory design workshop as outlined in Chapter 5, with each focus group session taking approximately 15 to 20 minutes. The focus groups were led by the primary researcher and were audio recorded in order to create a transcription of the session afterwards.

The sessions were held in a project room in the library building, where the participants sat around a table with the primary researcher. During each session, a set of six specific questions was displayed on slides presented on a monitor. These questions were adapted from those used in the survey, as outlined in Section 4.1, with minor modifications to gain a deeper understanding of the decision-making process of the students. Additionally, the participants were provided with a list presented on the monitor of library occupancy data types that varied in complexity and were asked to engage in a discussion about them. The complete set of presentation slides used during the session can be found in Appendix C.

Following the discussion, the participants were given a short questionnaire (Appendix D) involving the discussed data types. The data types presented in the questionnaire included today's visitors' history (1), same hour occupancy over the past 5 days (2), number of free seats (3), number of seats in use (4), and predicted number of seats available at 10 tomorrow (5). The participants were asked to rate the usefulness of each data type on a scale from 1, not useful, to 5, very useful, to provide specific feedback for further refinement of the data requirements of the system. The questionnaire also allowed the participants to describe or draw any other occupancy data they would find useful.

The data collected from the focus group sessions, including the recordings, transcripts, and questionnaire responses, were analysed using thematic analysis to identify key themes that emerged and provide insights for the system requirements.

4.2.3 Participants

The participants in the study were exclusively students enrolled at the University of Twente, recruited to take part in both the focus groups and the participatory design workshops as presented in Chapter 5. For the participatory design workshops, there was a particular emphasis on recruiting a specific number of students majoring in Creative Technology as it was essential for the effective conduction of the workshops, which relied on input and expertise from individuals with knowledge of rapid design and data physicalizations. Consequently, nearly half of the participants for the focus groups consisted of students majoring in Creative Technology. The other participants were from various academic disciplines to ensure a broad representation of perspectives and insights from the student body at the University of Twente.

4.2.4 Results

Three focus groups were conducted with 18 participants in varying group sizes: six, five, and seven for the sessions respectively. The distribution of majors among students included Creative Technology (8), Philosophy of Science, Technology, and Society (3), Educational Science and Technology (1), Business Administration (1), Biomedical Engineering (1), Electrical Engineering (1), Mechanical Engineering (1), Technical Computer Science (1), and Communication Science (1). Each focus group session was recorded, transcribed, and analysed thematically to extract overarching themes from the data. The tagged, raw data from the focus group sessions can be found in Appendix E.

The main objective of the thematic analysis was to identify patterns and trends in the responses of the participants regarding their decision-making process for selecting study locations and their behaviours related to studying at the library. The analysis revealed a number of themes, which are summarised as follows:

- *Library usage frequency*: The frequency of library usage among students largely varies, ranging from daily visits to only a few times per academic year. Some students make frequent use of the library and use it as their main study location, while others only make use of the library only at some moments during the module.
- *Reasons for library visits*: Students attend the library for diverse reasons, including the availability of a quiet and focused study environment, access to facilities such as monitors and project rooms, and the convenience of late opening hours. These factors influence their decision to study at the library opposed to other locations on the university campus or at home.
- *Preference for study locations*: The discussions from the focus group indicate that students have distinct preferences when choosing study locations. These preferences are influenced by factors such as convenience (study places near lecture halls), accessibility (late opening hours), availability of facilities (monitors and rooms for meetings), and the social atmosphere. It became apparent that students also often change their study location based on the need for focused study sessions, especially during exam periods.
- *Availability of study places*: During the third focus group session, the students were asked about their experience with the availability of study places in campus buildings. Most students said that they often have trouble finding available study places in busy times, such as exam weeks. However, other factors, such as the popularity of new buildings, also influence the crowdedness. Some students stated that they either seek alternative spaces to study, but also arrive early to secure a seat.
- *Decision-making process*: Students consider a wide variety of factors when making decisions about where to study, including the for focused work, the availability of facilities and resources, the location of the study places, and the overall convenience.
- *Usefulness of occupancy data*: When discussing the various types of occupancy data, the students expressed different perspectives on the usefulness for informing their study location decisions. While some students found the ability to access real-time occupancy information valuable for avoiding less crowded conditions, others suggest that more specific data, such as seat availability, project room occupancy, and noise levels, would be more beneficial for their needs. Only a few students acknowledged that they would not see use in this type of data as they would rather simply observe the situation in person.

In addition to these overarching themes, the thematic analysis identified nuanced insights and perspectives shared by the participants. Moreover, it became apparent that most of the students changed their study behaviours largely across years and modules. The discussions also revealed that each student has their own approach in finding the right study place, as they all have different needs to study effectively. Further details on the thematic analysis findings are presented in Table 3, providing an overview of the overarching themes extracted from the focus group discussions.

Table 3. Thematic analysis of three focus group transcriptions: session 1 (S1), session 2 (S2), and session 3 (S3)

Session	*Initial Coding*	*Emergent themes*	*Overarching theme*
Q: How often do you study at the library?			
S1	I don't never. Maybe like twice a year. I used to. Like in my bachelor I did, but now not anymore. I actually used to like to study quite a lot in library. Eh maybe once or twice per module. I just go there to study sometimes.	Frequent library visitor Occasional library visitor Rare library visitor Formerly frequent library visitor Not a library visitor	**Library usage frequency** The students vary in their frequency of visiting the library, from attending the library on a daily basis to a few times a month.
S2	Everyday, very frequently I would say. Almost every day. If I'm really busy then yes I will be here quite often, it differs quite a lot. I work here a couple of times a week At least once a week I come here. Mostly on the weekends I'm here		
S3	I very rarely visit the library. Maybe one time per two months. I also use the library very barely, once every two months. I did it a lot during my bachelor, but since my master, I don't think I really came to the library anymore. I come here every week. I also don't go to the library that often, maybe two or three times a month I'm in the library. I used to go the first semester of my first year, but now I don't go at all. Never yeah. I go about once a month		
Q: Why do you (not) visit the library?			
S1	Mostly when I have test week Depending on whether there's like an exam you actually have study for or not Group work quite often in the library When I can't find the space anywhere else on campus	Exam week Group work Availability Busy module periods Individual study Library resources Minimizing distractions Working alongside peers	**Reasons for library visits** Students visit the library for various reasons, including access to a quiet and focused study environment, facilities, and for convenience, such as late opening hours.
S2	Depends on the module If I don't have to study that much, then I won't be here at all		

	Depends on how busy I am I would go to Cubicus during the day and when it closes I come here I mostly come here to study by myself, but primarily to study there for exams or if I have to do some assignments or something, I come here and then use the big monitors. I usually study here for exams, sometimes I come here for group work. I also come here for the big monitors. I don't have an extra screen at home. And at home I get very distracted. I come here mainly to study by myself, to work with other in a project group, and the monitors if they are free. I do also like to meet other people that are not in my project group just to sit together in a room, but focus on my own thing. Working together so you can have a break together or something. Some of the project rooms are empty on the weekends, I also use the project room by myself. I also like the big white boards in the project rooms. Because I hate writing on paper, because then I just have just a lot of paper that I never use.		
S3	It's only in group projects when maybe someone else in the group has to plan it and then chooses the library. I'm also mostly with other people. If I can plan it myself, I'm usually not in the library either. Because of my honours group, we decided to meet altogether on every Saturday in the library. Usually because of other people When I'm feeling that I'm not being productive at home and then I get myself to go somewhere and where everyone is studying and then I come here.		

Q: So where else on campus do you study often? And why?

S1	Anywhere where I can find a space usually. Cubicus, and also the new ITC building. Because that's where our studies association is and that's where our, like the people that I know are. The ITC building and sometimes Ravelijn. Depends on where my classes are, I find a spot nearby, especially when it rains. EduCafe, because it's near where my study association is I normally just study like at home or at the library. When I really know I gotta really focus then I would prefer to go to the library. Last year at the ITC building and Horst because we had many lectures there, but now mostly at home. At home, at a friend's place, or at Cubicus.	Availability and accessibility Close to social circles Proximity to classes Level of distractions Building preference Food availability Work or project requirements	**Preference for study locations** Students have different preferences for study locations for different reasons. Study places are often chosen out of convenience and accessibility, while other places are chosen less due to their lack of certain facilities. The social aspect is often important for study spaces that are frequently visited, but when it comes to focused study sessions the preference goes out to quieter environments.
S2	It depends on the building. For example, I really like the ITC building, so if there's space, I would stay there. And if I'm in Ravelijn I would go there first because it's closer. But for example, if it's already like 6 and I need to stay for three or four hours, I will go immediately to the library because otherwise I have to move in the middle of studying and it just breaks my focus. But I will still be at the library more often because it stays open until late. And in the library it's mostly silent, so it's good to focus. Cubicus would be my number one and the library 2nd and then TechnoHal.		

S3	Cubicus or theater cafe as well. I don't actually have class in Cubicus, but it's because Idefix is there and P2 is there and P6 is there. For theater cafe, it's usually connected to like getting lunch or getting a drink. Cubicus almost every day, because my study association is there so you can just grab tea and coffee and everything. Sometimes carre, mostly in between classes then if I have class there. And theater cafe, if I wanna get a drink and that's maybe once a week probably. Honours office and interaction lab during my thesis, because my thesis equipment was there, so it made sense that I worked there as well. The Technohal, I don't actually have any lectures there but I just like the feeling, I think it's my favorite building. The Designlab, I don't like silence as much as I like background noise. For group projects and meetings DesignLab as well. For studying on my own, I'm at home, so nowhere on campus.		

Q: Is availability of seats ever a problem in the building you frequently study at?

S3	For Cubicus, because we are usually quite early, there's always a spot. Because we are usually with more people, you need a big table and if the big table is not available we can always go to the association room as well. When the Technohal was just opened and everyone started sort of crowding there, you could never find a table there. And now that Langezijds is open I wanted to sit there, you know, with the nice plants and everything and I thought, oh, that's cute, but then there's never space there. I think it also just depends on if it's exam season or not. I think also the library, like it's usually just full or the project rooms and then there has been multiple times where we had to sit outside at the cafe near the theater. DesignLab can be crowded, but there's always at least one spot somewhere, because it's usually also crowded, but people don't know about LearnX and Inspire and Inform. So I never, I almost never struggle with finding a room unless there's an event or something. Much more commonly would walk into the library and not find a space and then sit somewhere else in the Vrijhof.	Advantage of being early Availability of unknown or less frequently used study spots New facility crowdedness Variety of availability during module	**Availability of study places** Students note that some buildings are often quite busy due to their popularity or due to the exam weeks. Some students either diverge to less popular buildings or arrive early to claim a free space.

Q: What influences your decision to study somewhere?

S1	Depends on my mood and also of course like the obligations whether you have to be physically present at university or not. That's really, really dependent and whatever, how my concentration level for the day is, whether I wanna sit with people that I know, whether I don't wanna sit with people that I know. It depends per day where I go When I'm already on, like studying on campus, doing stuff I don't generally choose to go to the library that's more of a if it's planned in advance to go So for me it's like if would study at home, I know I'm probably gonna get distracted a lot and stuff and I just, the library is just this one, this is a place for me, also in my mind where I'm like, if I go there, I know I'm going to be able to focus. And then also last year, like during pretty much every project we would go to the library for pretty much 80% of all the meetings that we had.	Mood and concentration level Location Need for focus Availability of resources Separation of study and living space Study habit Social element	**Decision-making process** Factors influencing the decisions students make to study at a specific place include the need for focused work, the availability of facilities and resources, the location, and convenience.

S2	If I have to do a lot of like high focus work, I will probably go to the library. If it's a very small thing like I have to just like grammar check a report or something, I might do it from home because I don't wanna waste the trip here. Study in the library because I like to keep, as much as possible, my study space and my living space separate. Although I moved from campus to Hengelo, I was still at the library almost every day, especially during my thesis time. I was here like every day because I prefer to work on the monitors and they don't have an extra monitor at home. I usually study in the library if I just have a lot of work and I'm not already inside the building because of a lecture or something. Otherwise, I will just find a space in that building. If I'm home and then decide to go to the library, it's usually because I get easily distracted in my room. If it's a couple of hours then I'm going to the library. If I have more time then I sometimes also go to the SmartXP or a place where there's more distraction. Uhm, but I also like the idea of not doing it at home, because then you're at home and then it's your own place and then you're free and keep the studying part separately. I live on campus, so it's easy to come here and I come here when I want to deep focus as well, also encourage me when other people are studying.		
S3	I used to go to the quiet section of the library, but it's just not respected. People are very frequently talking, walking into it. The social element is important, I think. And I usually have meetings during the day sometimes. So then it's nice at I'll have the, so if if you're in a quiet spot you cannot take the meeting there, but you're also not sure if there's a project room or something I also think that it's central on campus. So, when you're at Cubicus you can very easily move between buildings, if you have things in between. Whereas I feel like if you're in the Horst, for example, that's less. The number of distractions. When I still used the Citadel, so the Interaction Lab, I would go there if I sort of wanted to be left alone and just work on my thesis project. Then I would sit and what I do now is sit in the Honours room if I sort of allow myself to be found by people who like need to have me for something.		

Q: Which data types would be useful to you? And why?

S1	I wouldn't check it every day, but maybe in like exam weeks when you know the library is gonna be very full and it could be nice to see which spots are actually taken. Because usually it's not too busy in the library normally and you could find a spot. I would say I would maybe check only when it's like actually busy the last two weeks of the module, maybe. I wouldn't really care about the predicted number of seats. Just the real time data. I would just check it to see if there is something available and then go there. Normally when I also go in, I just check on the booking site like is there a room available right now	Useful during busy times Occupancy of specific seats Would not use the data in their decision-making process Useful for frequent visits Occupancy of project rooms Occupancy trends Noise level	**Usefulness of occupancy data** Some students see the advantage of having access to real-time library occupancy data to check if the library is not too crowded. Other students suggest that more specific data would be more valuable to them, such as specific seats, monitors, project rooms, occupancy trends, and noise data.

	I wouldn't honestly care about any of these numbers. I prefer just to go there and see. I don't like checking data		
S2	I would definitely think it's useful, especially if I am deciding. Depending on how busy it is, I might go to a different building. The number of visitors that are currently in the library is also helpful. I would say it's useful when deciding if I wanna go to the building or not. If there's too many people in the library then it's just too distracting. To see if there are actually places you can sit at. I know during exam weeks it's very packed in here and then I have to go all over to look for a place to sit and then I don't find a place to sit and then I have to go sit in another building or something. So, it's useful then to know. The facilities, the extra screen, sometimes they are also not free anymore. So then I also have to go somewhere else. I think the area because they have different areas for the library. It would be nice to see if there are any free ones instead of just walking around all of them.		
S3	Data showing if it is typically busy or typically not busy stuff, I think I would be more interested in that than maybe the exact number of seats. I think for me that the number of free seats would be useful to see if, yeah, in those really crowded moments, which in my case I only go to the library when I have a deadline and I'm not concentrated at home, which is usually aligning with exam periods, which is also the busiest time. So already knowing in advance that there is at least one free seat for me somewhere in the library that would be useful information. To not just go and waste time. I don't know about free seats, because if it takes me a bit of time to get to the library, knowing there's exactly 5 seats left doesn't mean much because it's probably gonna change by the time that I get there. But like a general, I don't need that much detail, but if I can see the past how full it was and then the now so like a general how much people are in the library graph, then I can compare it. I would also be interested in seeing how many project spaces are free. I think I mean, I would also like the trend of how busy it is because that's sort of I think for me it's more about distractions. But if I would know what sort of noise is, if it's more than usual, then I think I probably will not go even if there are plenty of seats. I think it would be more like I'm fine with there being a lot of people just as long as they don't distract me I guess.		

4.3 Conclusions

The survey and focus group sessions revealed several key elements in the decision-making processes of students regarding library visits and choice of study location. Additionally, the results reveal a variety of opinions on the usefulness of specific library occupancy data types and insights in how students would use this information in their decision making. These findings are essential for developing an effective method for communicating library occupancy data to students that aligns with their diverse needs. In this section, a summary of the key findings of the survey and focus groups are discussed and some conclusions for the requirements of the system will be presented.

The survey indicated that most students plan their library visits ahead of time, often while being at home. However, a significant number of students are already on campus when deciding to go to the library, indicating the need for a system that offers accessibility from various locations. While real-time occupancy data might not be of interest to those who plan their library visit ahead, more sophisticated data, such as occupancy patterns and predictions, could have greater value to them. Overall, students expressed to be positive towards using occupancy data in their process of deciding to visit the library, though their data type preferences varied depending on their study goals and needs.

The focus group discussion revealed more specific factors influencing the selection of study places by students. The quiet environment and late opening hours of the library were some of the key reasons for its regular use as a study place among students. Additionally, a recurring concern was the lack of information on the availability of project rooms, as students said they frequently encounter unavailable study rooms when they want to study together and that, as a result, choose to visit the library less often and diverge to buildings with more study places. Therefore, knowing the real-time occupancy of the project rooms would allow these groups of students to more frequently visit the library.

Regarding the occupancy data types, the survey indicated diverse interests among students, with more than half of the survey respondents showing interest in multiple data types. The focus group discussions supported this, as most of the participants indicated how they would use the information in their decision-making process. Although real-time library occupancy data in terms of the number of free seats seems to be the most popular among the discussed data types, the suggestions of the students reveal that area-specific and more sophisticated data would be even preferable. Metadata about the type of seats available of the real-time occupancy information would give the students more context about the situation inside the building as well as allow them to know the occupancy levels of specific library seats, such as desks with monitors or seats in the silent area. Sophisticated occupancy information, such as historical patterns and predictions, allow students to analyse the data more profoundly and understand the indoor situation better.

These insights show the importance of developing a system that not only collects relevant occupancy information but also presents it effectively to students. Accessibility from multiple locations, inclusion of sophisticated data, and mechanisms for user feedback are important considerations for such a system. A combination of presentation methods, that are tailored to the needs of both remote users and those inside the library, could further enhance the usability, accessibility, and effectiveness of the system. For instance, a mobile application offering a range of sophisticated occupancy data types may be useful for remote users, while area-specific, real-time data presentations could assist students inside the library in locating available seats.

5 Participatory design study

In this chapter, an overview is provided of the participatory design study carried out at the University of Twente for this research project. First, the outline of the study setup and its outcomes are presented. Afterwards, insights into the analysis of the study results and a detailed description of the process of exploring the design space for physicalizations of library occupancy data is given.

5.1 Objectives

The participatory design study aimed to investigate the potential design options for physical representations of library occupancy data, by involving the main user group: students at the University of Twente. The main goal was to have the users collaborate in a creative process to generate diverse ideas for library occupancy data physicalizations during participatory design workshops. The results from these workshops served to explore the range of possibilities of physicalising library occupancy data and gather insights from the students about these designs to address the sub research question concerning the physicalization aspect of communicating library occupancy data as described by RQ1.6:

- RQ1.6: How would they want the information about library occupancy to be physically communicated?

5.2 Study design

The study involved participatory design sessions aimed to involve users in the creation of physicalization ideas for library occupancy data. In total three workshops were held consecutively over the course of three days with students in the library at the University of Twente. The workshops were composed of three main components: an introduction, a focus group, the main design session, and a presentation and discussion.

The study involved three workshop sessions, including a pilot session to refine the format and flow of the workshop based on the outcomes and participant feedback. The other two sessions were differentiated based on the intended environment for the data physicalizations: one session focused on the private audience, such as a home environment or something carried by the user, and the other session focused on the semi-public audience, such as the university campus or the library building. This division was deliberately chosen to allow for a targeted exploration of physicalizations designed to integrate into different contexts, thereby enriching the diversity of the design ideas by default.

The data collected from the design workshop sessions, including the audiovisual recordings and photos of the generated designs, were analysed using a mixed method approach with integrating structural coding and reflexive thematic analysis, as outlined in Chapter 3, to define the design space for physicalizations of library occupancy data.

5.2.1 Workshop procedure

Each of the workshop sessions was documented through audiovisual recordings and pictures were taken of the outcomes. Ethical approval for the study was granted by the University of Twente Ethics Committee. Before the start of the workshop, participants were briefed on the workshop details through an information letter and provided consent for their involvement. These documents can be found in Appendix F. The session took place in an office within the library, equipped with seating, tables, and a large smart monitor for displaying the slide presentation during the workshop, as shown in Figure 17. Since the sessions were held around dinner time, food and water were provided for the students during the workshops.

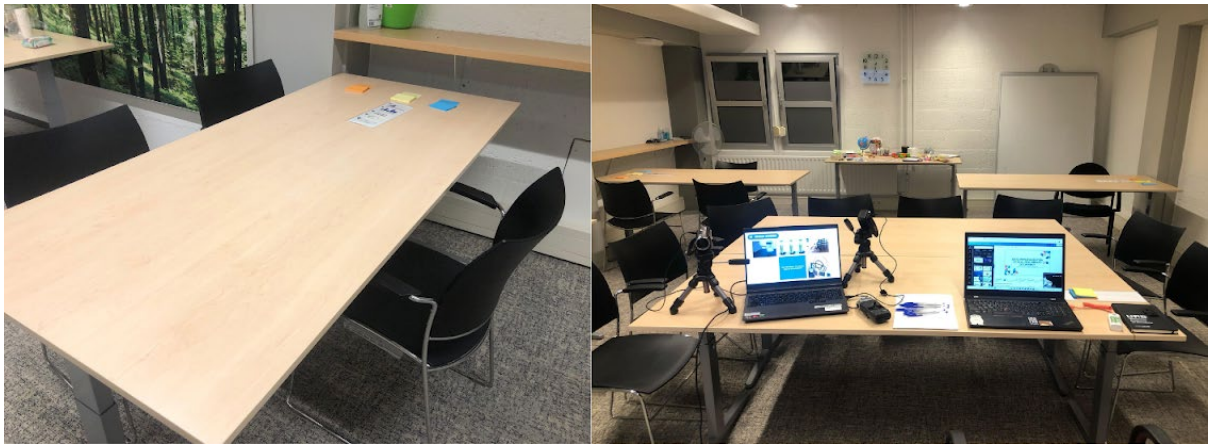

Figure 17. The office where every workshop session was held: left) one of the design tables with brainstorming aides at the upper end of the table, right) a view of the entire room with the centre table where the introduction and focus group were held, in the back there are three tables, the centre table contains the workshop materials whereas the tables at the sides are for each group during the design session.

Phase 1: Workshop introduction

Each workshop session began with a 10-15 minute presentation to provide the participants with an overview of the research project, an outline of the activities and objectives of the workshop, and to familiarise them with the concept of data physicalizations. To effectively teach participants about the concepts of data physicalizations, the presentation included a large variety of examples, as shown in Figure 18. This introductory phase was essential in ensuring a common understanding of the workshop aims and the concept of data physicalizations among all participants. The slides of the entire presentation are available in Appendix C.

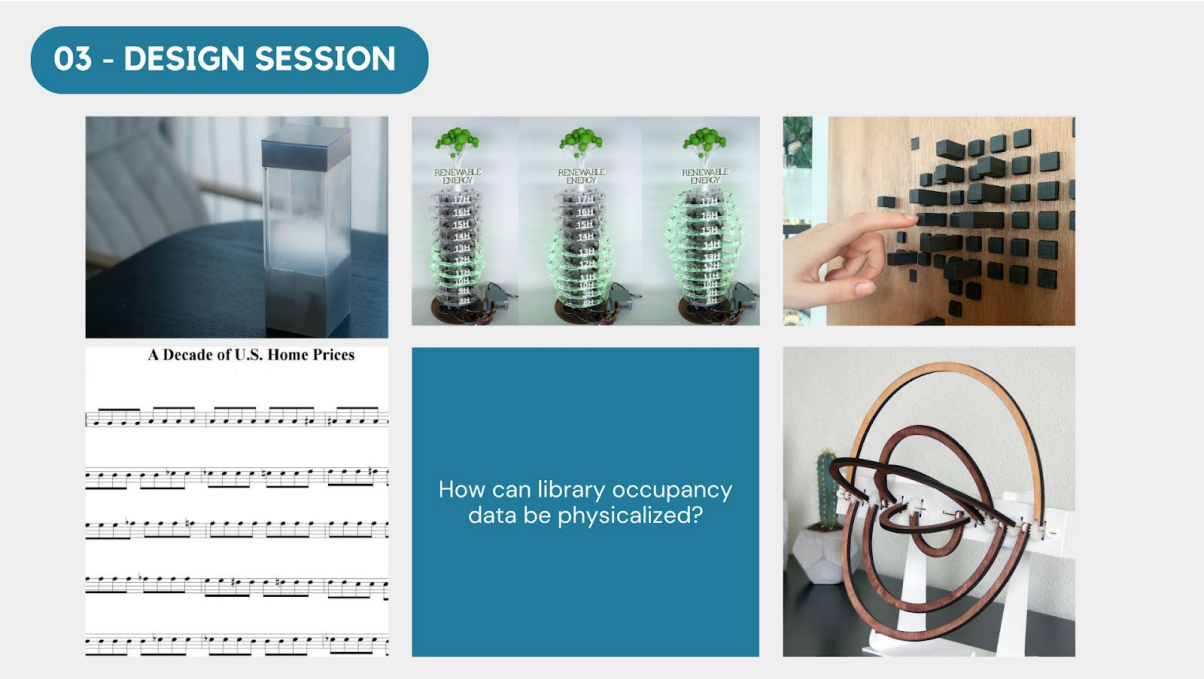

Figure 18. One of the slides demonstrating the discussed data physicalization examples that were used to familiarise participants with this concept during the participatory design workshops: topleft: The Tempescope [54], top centre: CairnFORM [34], topright: Laina [40], bottomleft: US home prices sung as opera [55], bottomright: LOOP [39].

Phase 2: Focus group

After the introduction, the participants engaged in a 20-minutes focus group session about their decision-making process regarding library usage and choice of study place, further detailed in Section 4.2. This session served not only to gather insights from the participants but also acted as an icebreaker, allowing the participants to familiarise themselves with one another. In this way, this discussion element was used to set a collaborative and interactive tone for the rest of the workshop.

Phase 3: Design session

The main part of the workshop was the design session, where participants were divided into small groups of two to three people to engage in a collaborative, creative process to generate physicalization ideas for library occupancy data. The prompt for the design session was shown on the large monitor in the room, see Figure 19. The groups all had a table with space to brainstorm and ideate design ideas and were provided with a variety of materials to support this collaborative process as detailed in Section 5.2.2. The participants were given 25-30 minutes to engage in the design process. Five minutes before the end of the design session, the participants were notified with the time left until moving to the next phase.

Phase 4: Presentation and discussion

Lastly, the groups were asked to stop their design process. Then each group was asked to explain each of their designs, explaining what data was physicalized, how this data is presented, the intended user interaction, and the intended placement of the physicalization concept. Afterwards, the researcher and other participants could ask questions and discuss the designs based on their novelty, applicability, and usability.

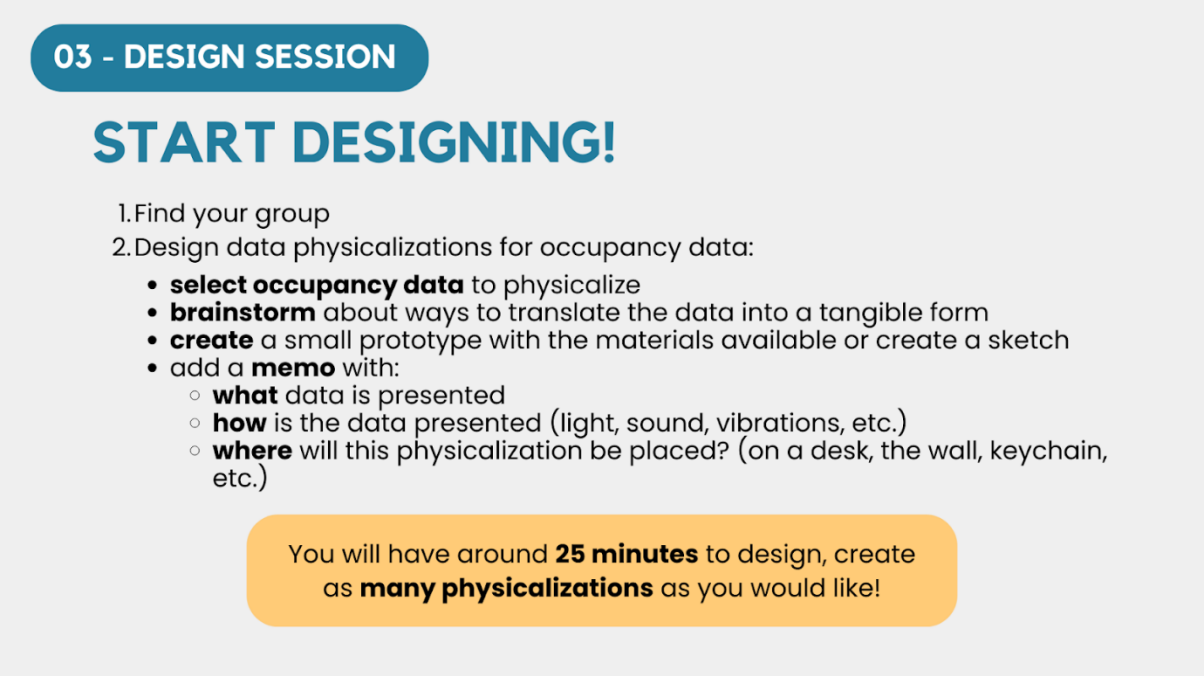

Figure 19. One of the slides showing the design prompt during the participatory design workshops.

5.2.2 Design materials

To support the creative exploration during the design phase of the workshop, a variety of materials was provided to facilitate the development of a design from brainstorming to rapid prototyping within the constrained workshop time frame. These materials consisted of three distinct types, each supporting a specific purpose in the design process: the data types for the physicalization, brainstorming aids, and physical prototyping tools.

Data types

On the design tables, each group was provided with laminated sheets that outlined five types of occupancy data, as shown in Figure 20: 1) today's visitors history, 2) same hour occupancy over the past 5 days, 3) number of free seats, 4) number of seats in use, 5) and predicted number of seats available at 10 A.M. tomorrow. These data types, which can already be derived from the existing data collection system of the library, were selected to ensure their relevance for potential future creation and implementation of a data physicalization.

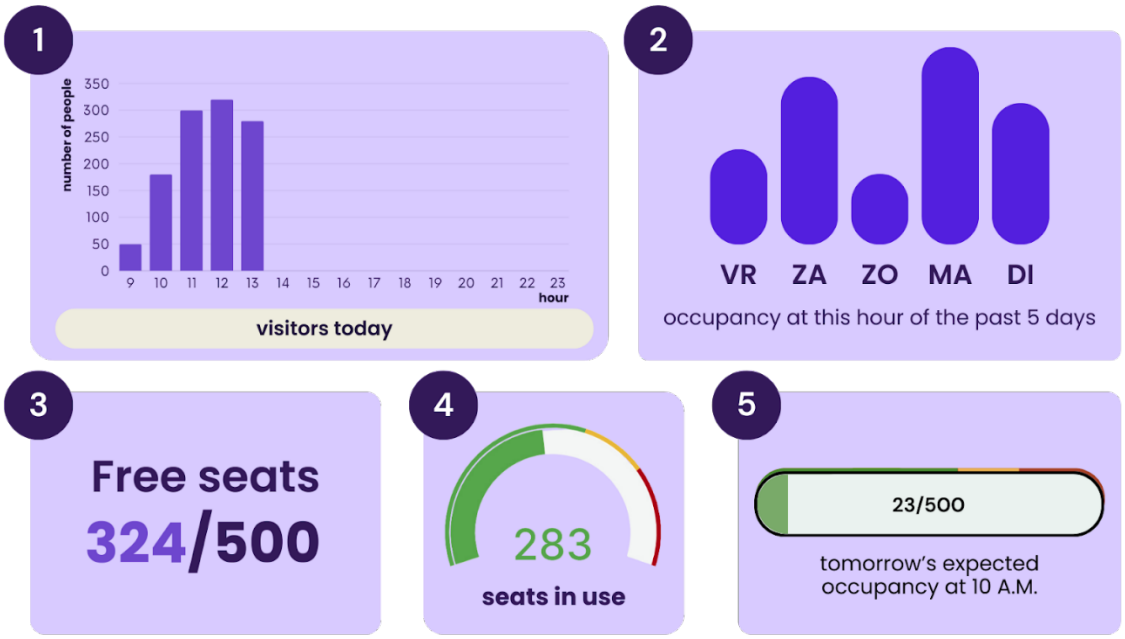

Figure 20. Library occupancy data types made available for each group during the participatory design workshop.

Brainstorming aids

To guide the brainstorming process and articulate design concepts more thoroughly and effectively, three sets of coloured memos were placed on each table, each colour corresponding to a specific guiding question: orange for the type of data being physicalized, yellow for the method of data translation, and blue for the intended placement of the physicalization. Illustrated in Figure 21, these prompts were chosen to let the participants think about the functionality, contextual application, and user interaction of the proposed designs.

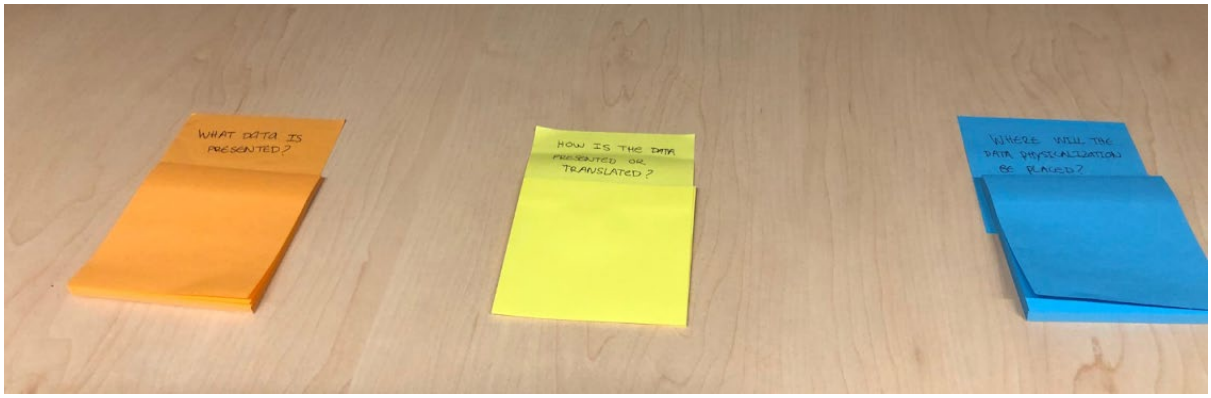

Figure 21. Three piles of coloured memos with guiding questions placed on the design tables for each group during the participatory design workshop.

Physical prototyping tools

In the space where the workshop was held, one table was placed centrally, filled with a variety of materials intended for the creative development of the concepts and low-fidelity prototypes. This collection was composed with the idea to assist the participants in their creative design process in multiple ways, including:

- *Physical design materials*: an assortment of design items such as small wooden pieces, play dough, metal wire, tea lights, beads, clips, elastic bands, feathers, thread, popsicle sticks, toilet paper, fibre balls, wooden domino sticks, hooks, and a small globe. These materials were provided to encourage the participants to physically model their design ideas.
- *Drawing materials*: to enable the participants to sketch or draw their design ideas by using coloured pens on paper or with markers on small whiteboards.
- *Physicalization prompts*: laminated cards with printed words suggested various materials and phenomena for participants to consider incorporating into their designs. Given the short time frame of the workshop, this was done to give the participants some material inspiration for their physicalization designs. The prompts included water, light, paper, sound, elasticity, magnetism, temperature, vibration, colour, sand, fibreglass, and wire.
- *Tools*: Scissors, tape, and glue were also provided to assist in assembling the low-fidelity prototypes.

Figure 22 shows the physical design materials provided during the workshop, while Figure 23 shows the various materials used by the participants in their creative design process. The range of materials was specifically integrated into the design workshop to facilitate the tangible expression of design concepts and to inspire creative thinking by encouraging participants to engage with various textures, forms, and functionalities in their physicalization designs.

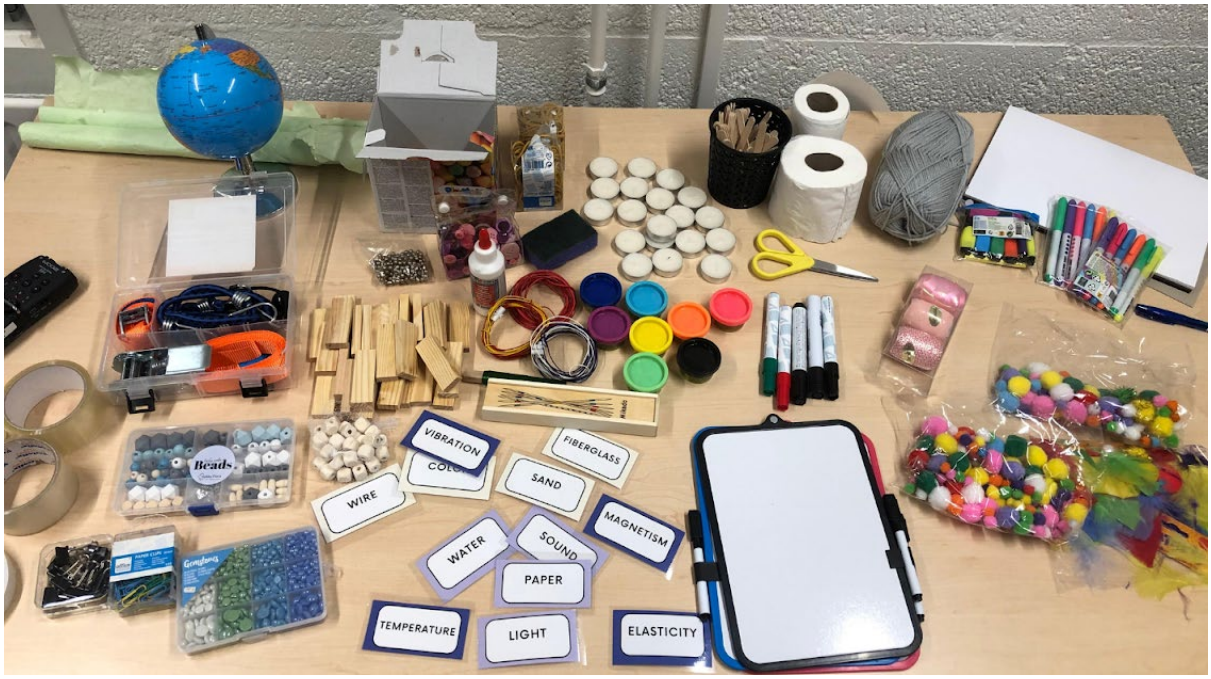

Figure 22. A table filled with materials placed in the workshop space, with physical design materials, drawing materials, physicalization prompts, and tools to enhance the design process of the participants.

Figure 23. The participants engaged in the creative design process using the brainstorming aids (left) and physical design materials (right).

5.2.3 Participants

The participatory design study involved exclusively students enrolled in the University of Twente. While the students from all majors were recruited to partake in the study, there was a specific emphasis on the inclusion of students majoring in Creative Technology due to their specialised knowledge in rapid prototyping and data physicalization concepts. This emphasis was seen as essential as it was expected that for conducting effective design sessions, involving Creative Technology students in each design group could enhance the dynamics and effectiveness in the collaborative design process. To ensure a diverse range of perspectives for the physicalization ideas, the workshop involved a good balance of students from different disciplines. This multidisciplinary recruitment approach aimed to mirror the diverse user base of the university and the library and allowed for the exploration of physicalization concepts from a wide range of perspectives.

5.3 Outcomes

There were three workshop sessions conducted, involving a total of 18 students from the University of Twente, with a distribution of majors as described in Section 4.2.4. The number of participants of the session was as follows: the initial pilot session had six participants, the session focused on the private audience had five participants, and the session with a focus on semi-public audience involved six participants. During the workshop, participants were actively engaged in the creative process to create a variety of data physicalizations. This was captured in Figure 24, where students can be seen working together, utilising the materials provided to develop their physicalization designs. In total, 26 data physicalization ideas were generated, of which 14 were created in the private audience session and 12 ideas stemmed from the semi-public audience workshop session. Detailed descriptions of these physicalization concepts are presented in Section 5.3.1, providing further insights into the outcomes of the workshops. These descriptions are then further analysed to determine the design space in the remaining sections of this chapter.

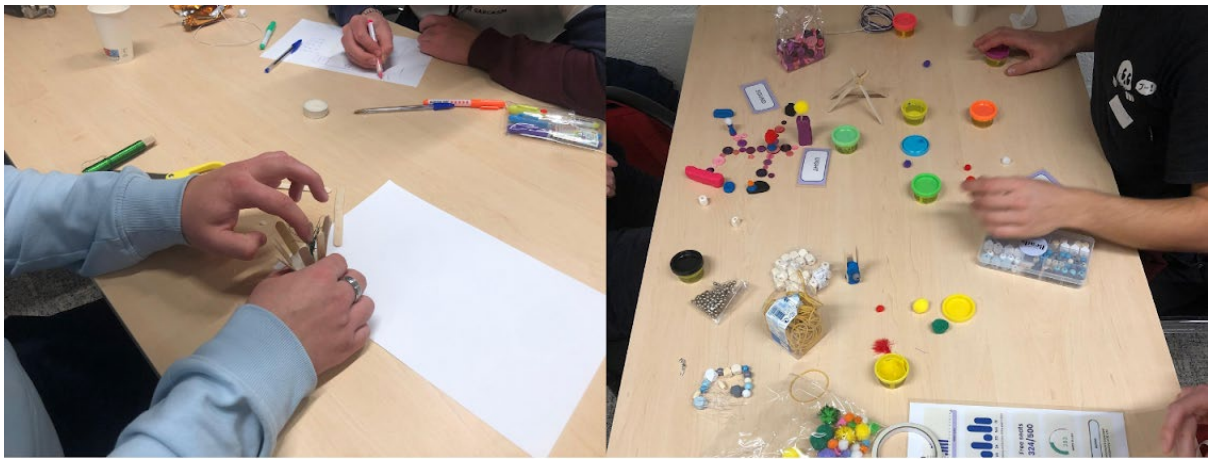

Figure 24. Participants engaged in the design process during the participatory design workshop.

5.3.1 List of extracted ideas

The workshop sessions led to the generation of a diverse set of 26 data physicalization ideas. These ideas were explained by the participants supported with their created low-fidelity prototypes, design drawings, or explanations in text, as shown in Figure 25. Following below, the specifics of these data physicalization concepts will be described to offer a detailed overview of the entire set of concepts. The first 14 ideas stem from the design workshop session focused on the private audience, while the remainder of the ideas were created in the workshop focused on the semi-public audience. In later sections and chapters, the ideas will be referred to by their identification number, such as I1 for idea 1, and by their name.

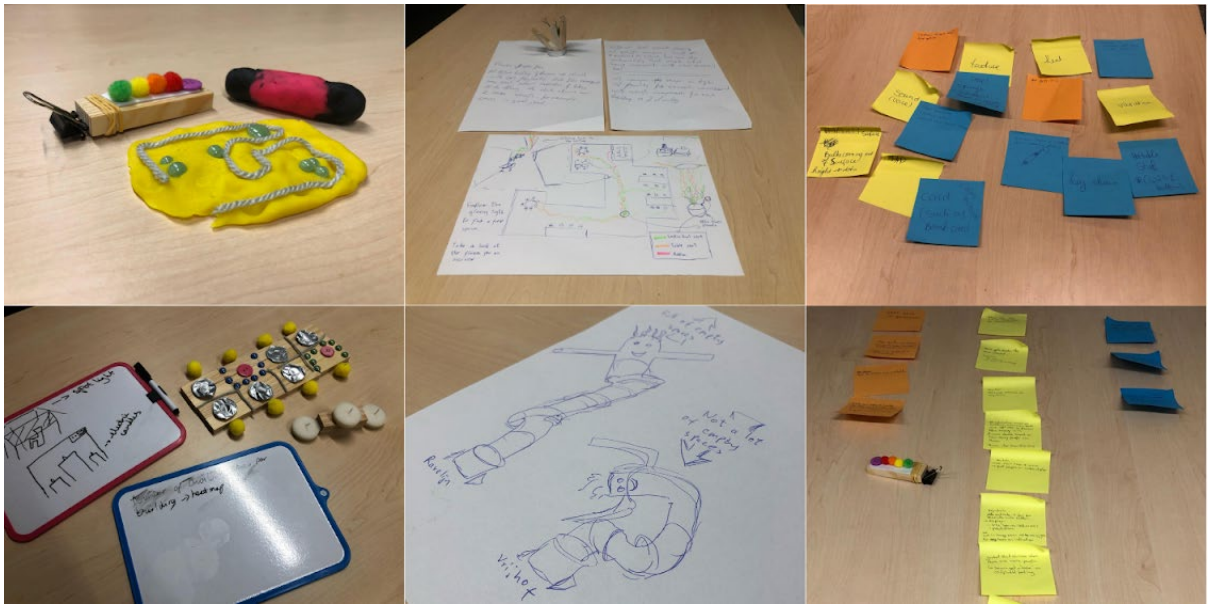

Figure 25. The materials used to ideate and explain physicalization ideas during the workshop, left) low-fidelity prototypes using physical materials, centre) drawings and explanations of more complex data physicalization system ideas, right) data physicalization ideas explained with an abundance of coloured memos.

Idea 1: Colour-changing keychain

One group presented a number of ideas for utilising a keychain for showing library occupancy data. This first idea was inspired by a lava lamp, featuring a vertical, circular design with electronic components encased at both ends. In the centre there is a transparent unit filled with a liquid chemical capable of changing colours, as shown in the low fidelity prototype in Figure 26. The chemical composition in the centre is altered to emit different colours of light, corresponding to the number of people in the building. For instance, a green light could indicate low occupancy, yellow light a moderate level, and red light a high level of occupancy. As users can carry and quickly access the device, it provides an immediate visual cue of the library's current occupancy state.

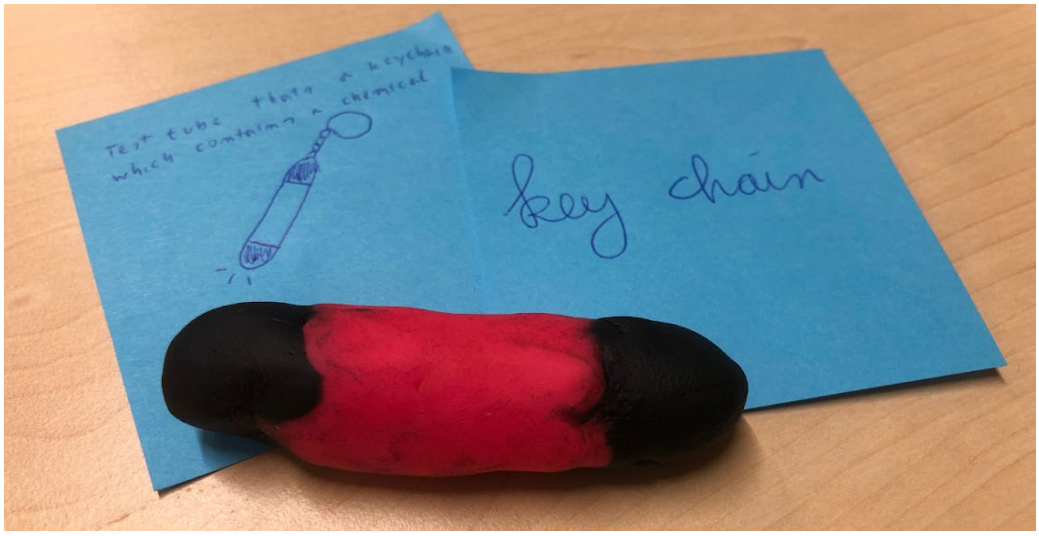

Figure 26. Colour-changing keychain: this prototype showcases a keychain featuring a central transparent unit with a liquid chemical capable of emitting varying colours corresponding to library occupancy levels.

Idea 2: Vibration keychain

Another keychain that was proposed utilises vibrations as a medium to convey occupancy data. The keychain is designed with a button that can be pressed to let the portable device vibrate to signify the library's occupancy level. The intensity and duration of the vibration correlate with the number of people present in the library. For example, gentle, short vibrations would indicate low occupancy and intense, long vibrations for high occupancy levels. Additionally, buttons could be added to the keychain to give users the ability to select different areas within the library or other buildings. Alternatively, the single button could be used to select specific areas with different press sequences, although this would require users to memorise the sequences.

Idea 3: Thermal keychain

A third keychain that was presented translates the library's occupancy level into thermal feedback. The keychain changes temperature based on the number of people present in the library. The device would be cool to the touch in low occupancy situations and would gradually increase its temperature as the space becomes more crowded. When the library is completely occupied, the keychain would be at its warmest.

Idea 4: Sound keychain

The following keychain idea was proposed by the participants based on soundboard technology. The keychain features a small board equipped with multiple buttons, each representing a different area within the library. By pressing a button, the user is able to trigger a sound that reflects the occupancy in the selected area. The occupancy level could be translated through the sound level or with the type of sound. For example, a soft sound could indicate few people, while a louder sound corresponds to a higher occupancy. Alternatively, or additionally, the type of sound could represent the occupancy level. Where for example a calm nature sound could present low occupancy and the sound from a thunderstorm could indicate high occupancy levels.

Idea 5: Light keychain

The last keychain idea that was proposed utilises the concept of a traffic light for its design. The device features a number of LEDs in a vertical line, much like a traffic light, with a colour spectrum ranging from red to green. A button is integrated into the keychain that upon being pressed lights up one of the LEDs, as can be seen in the low fidelity prototype in Figure 27. The library's occupancy data would be translated into this spectrum range of colours. For example, red would represent more people in the library and green indicates a less crowded situation. Additionally, if the button is pressed multiple times or in a certain pattern, other information, such as the occupancy in specific areas, could also be presented.

Figure 27. Light keychain: a physicalization equipped with vertically aligned LEDs that light up in colours from red to green based on the library's occupancy, activated by a button (purple bead) press.

Idea 6: Library map card

Another portable idea that was proposed came from the concept of a card, such as a bank or transportation card. The card would show a small map of the library and the levels of occupancy would be indicated through certain areas that would light up as demonstrated with green beads with various sizes in the low-fidelity prototype of Figure 28. For example, study areas or places that are free could be lit up on the map, whereas occupied places would stay dark. Alternatively, the card could show exactly the opposite, where there are more people, there is more light shown. The colour of the light could allow for showing both the free spaces and the most crowded areas. In this case, the areas on the map could have a red colour indicating high occupancy, whereas a green colour could show low occupancy. This could be integrated into the student card of the university where the library is located.

Figure 28. Library map card: left image) a portable card (yellow surface) displaying a miniature map of the library (grey wire), where areas are illuminated (green beads) to indicate the occupancy status of different zones, right image) the comparison of the prototype with an actual transportation card.

Idea 7: AR Smartwatch

An idea that was proposed utilised the technology of smart-watches and augmented reality (AR). In this concept, if a user wears some device on their wrist, like a smart watch, it can project a 3D digital twin display of the library above the device's surface using AR technology. To view this digital twin, the user would need to wear either a headset or AR glasses. The digital twin provides visual cues through colour indications, enabling the user to see the varying occupancy levels throughout the library.

Idea 8: Responsive jacket

Another idea that was proposed involved a specialised jacket that can be worn by students. This jacket has the ability to contract when the occupancy in the library increases, providing a direct pressure on

the upper body of the user. Conversely, when the occupancy is lower, the jacket expands and relaxes, losing its grip on the body. This approach simulates the sensation of crowdedness in an environment, letting the user physically feel the changes in occupancy.

Idea 9: Elevating library map

A number of ideas that were proposed during the design workshop included objects that can be placed on a desk or on a flat service. Among them is a desk-sized object that was proposed that includes a 3D map of the library. The occupancy level of the different library sections is represented through the varying elevation of these sections within the object. Each area rises in height proportional to the number of people present in that space. The scale of elevation is relative, with the lowest point indicating an empty area and the highest elevation showing maximum occupancy.

Idea 10: Miniature building

A second desk-sized concept that was presented, involved a miniature version of the library building. By pressing a button, users can activate the miniature object and observe certain areas being lit up within the small building. The lights serve as indicators of occupancy of specific areas in the library. For example, areas with many seats available, may be highlighted with brighter or lighter tones. On the contrary, areas with high occupancy levels are shown using dimmer or darker tones. Additionally, the design allows for the incorporation of LEDs that specifically indicate seats, showing that they are free or occupied through the use of light.

Idea 11: Responsive sculpture

Another idea of a desk-sized object dynamically translates library occupancy data through physical expansion and contraction in art sculpture. This sculpture is able to grow or inflate when the library is highly occupied and can decrease in size or deflate when occupancy is low. Materials such as sponges that absorb water, or objects that expand with air, such as balloons could be utilised to create this sculpture. The sculpture could be placed at home on a desk as decoration, but also be put at the entrance of buildings.

Idea 12: Responsive plant

Building upon the idea of items that can be placed around the house, this concept utilises the growing character of plants to demonstrate library occupancy levels. The (conceptual) plant grows taller or extends its form to reflect a high occupancy level in the library, while it contracts or diminishes in size when the library is less occupied. Instead of using natural plant materials, the design could be a plant-like structure with integrated LEDs and other materials. In this way, the growing effect of plants can be done by lighting up more LEDs and diminish in size by switching them off. This plant could be placed at home or at the entrance of the building, where users can grasp the crowdedness of the library through observing the plant.

Idea 13: Adaptive painting

An artistic idea that was proposed by one of the groups translates occupancy data in a painting. This digital painting can change its style according to the level of occupancy in the library. For instance, a quiet scene showing still water with a lone boat may represent a low occupancy level. In contrast, a high occupancy level may be illustrated through a vibrant cityscape, with illuminated windows and crowded streets. While this digital painting can serve as an indicator of the crowdedness in the library for university students, it is simultaneously a visually appealing and aesthetically pleasing artwork that can add an artistic element to the environment.

Idea 14: Ambient music

An idea that moves away from visual and tactile cues, was introduced by a group suggesting the translation of library occupancy data into music. In this idea, the music's volume intensifies as the library becomes more crowded and the style of the music changes to reflect a busier ambiance. Contrastingly, when the occupancy decreases the volume of the music lowers, and its composition becomes simpler, having fewer instruments playing at the same time or less complex arrangements. This presentation of library occupancy data could be played in various settings, such as at home, at the entrance of a building, or even on personal devices like phones or laptops.

Idea 15: Overhead light indicator

Diverging from the ideas focused on library occupancy data, this concept involves converting noise data into visual cues using light. In this system, the sound level in each area or at each seat within the library is monitored. When the noise in a specific location exceeds a predefined threshold, lights positioned above this area would light up in a distinct colour, such as red. A low-fidelity prototype created during the workshop demonstrates this functionality in Figure 29. This serves as a signal to library users, making them aware of their noise levels and encourages them to behave more quietly. Additionally, this light system can also function to indicate the availability of seats. For example, a green light can indicate a green space, if there is no light it means that the place is occupied, and when the light is red it means that the user is too loud.

Figure 29. Overhead light indicator: left image) top view of the low-fidelity prototype demonstrating the noise-monitoring system where overhead lights change colour, with the pink beads on the blocks to indicate the overhead-coloured lights, a table represented by the wooden blocks, and the yellow fibre balls as chairs, right image) close-up view of the prototype.

Idea 16: Candle display

One group presented an idea to display project room occupancy data using a desk-sized object. This object features a display with small (electric) candles, one for each of the project rooms. The real-time occupancy data of these rooms is conveyed through the candle's light, as depicted in Figure 30. A lit candle indicates that the room is occupied, while an unlit candle means that it is available to use. The design mirrors the concept of warmth generated in a project room when it is in use, with the lit candle service as a metaphor for the presence of people and activity within the space.

Figure 30. Candle display: left image) whiteboard drawing with an explanation of the physicalization idea, indicating a desk-size display featuring electric candles representing project rooms, where the candle is illuminated to indicate the room occupancy, right image) close-up view of the low-fidelity prototype created with tea lights.

Idea 17: Library fountain

Another physicalization idea that can be placed at the entrance of a building, features a small fountain. This concept translates the number of people present in the building into the water flow of the fountain. Specifically, the fountain increases the amount of water it propels upwards in direct correlation with the increasing number of library occupants. As a result, when users pass by the fountain, they can grasp the level of occupancy of the building by observing the height and volume of the water.

Idea 18: LED map

The following idea involves a map that can be mounted to the wall and translates library occupancy using light. This map includes a layout of the library with each seat or space represented by a LED light. While passing by, users can easily observe it to understand the current occupancy in the library: the colour of the LEDs signify the occupancy status of each spot. For instance, green lights indicate free seats, red lights show occupied study spaces, and yellow lights indicate seats that are currently free but reserved and will be soon occupied. Additionally, the map can display the exact number of free seats and project rooms, either as text or through progress bars. This feature offers users a direct understanding of the library's crowdedness, as opposed to a more dispersed and less immediate interpretation provided by the individual lights. Figure 31 presents the low-fidelity prototype of this idea that was created for this physicalization idea.

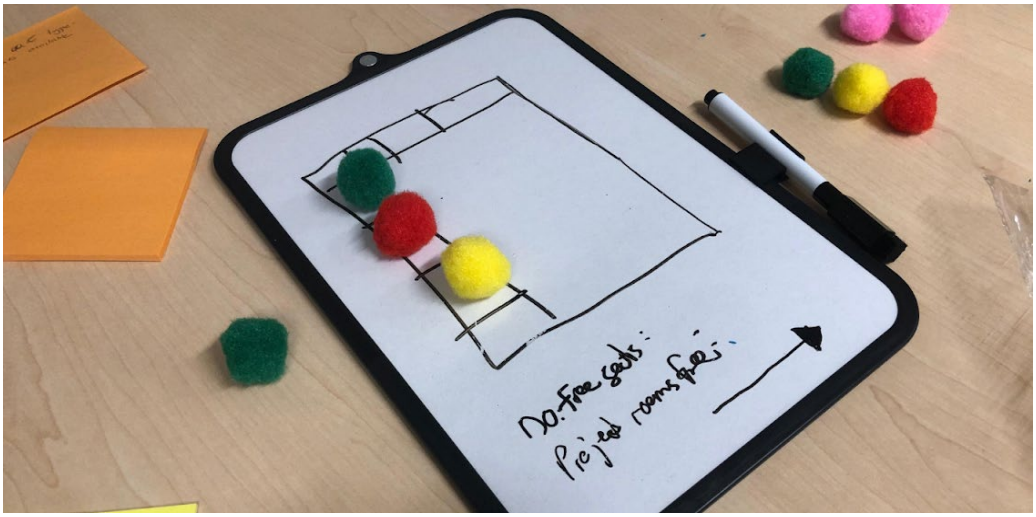

Figure 31. LED Map: the whiteboard shows the idea where the drawn boxes indicate tables in the library and the coloured fibre balls represent the colour indication corresponding to the occupancy status of the tables.

Idea 19: Footprint projection

Another idea that is intended to be displayed at the entrance of a building, uses visual projections on the floor to represent the occupancy of the library. Upon entering the building, the footprints of a visitor are projected onto the entrance floor. These footprints remain visible as long as the individual is inside the building and disappear once they exit. The density of these projected footprints on the floor directly correlates with the real-time number of people in the library. This method provides students with an immediate and intuitive visual cue of the current occupancy level.

Idea 20: Magnetic art piece

A more artistic concept was introduced by one group that involves an art installation with metal balls and adjustable magnets. This piece operates by rearranging magnets to form a specific number on the wall. When activated, metal balls are released from above the installation, with some balls remaining suspended in mid-air, held by the magnetised numbers. This creates a visual display of a number, representing the current occupancy of the library. In this way, passersby can easily observe and interpret this number formed by the metal balls. After a set period, the installation resets itself. The art piece can be activated either by users pressing a designated button or automatically through motion sensors detecting movement near the installation.

Idea 21: Interactive animatronic

An idea that was proposed features an interactive animatronic as a means to communicate library occupancy data to passersby. Placed at the entrance of the building, this animatronic is designed to speak and respond to users through speech. It can be activated by detecting movement or can be prompted through auditory cues, such as spoken words from users, or by pressing a button. The animatronic is provided real-time data on the occupancy of the library and can provide specific information about different areas within the library. Additionally, a network of these animatronics could be placed across the university campus in multiple buildings. This network would enable the animatronic to share occupancy information from multiple locations, offering an interactive and informative experience for students moving throughout the campus.

Idea 22: Fibre optic flower

This idea involves the integration of a fibre optic cable system within the library building. Central to this concept is a fibre optic ‘flower’ that is located at the entrance of the library building. From this flower, cables extend across the ceiling to various study areas and places within the library. The illumination of a fibre optic cable signifies that the corresponding space is available for use. Moreover, the colour of the cable indicates the type of space: green for individual seats, orange for table seats, and pink for project rooms, illustrated in the left picture of Figure 32. At the entrance, students can quickly assess the overall availability of spaces by observing the flower, where all the fibre optic cables come together, as shown in the low-fidelity prototype shown in the right picture of Figure 32. Afterwards, students can easily find and follow the specific-coloured cable on the ceiling to reach the specific type of study space. Additionally, every building with study spaces could feature a similar central display, surrounded by smaller flowers that indicate the real-time occupancy of other buildings on campus. This system provided a visual and intuitive method for students to navigate and find available study areas within the library and across the campus.

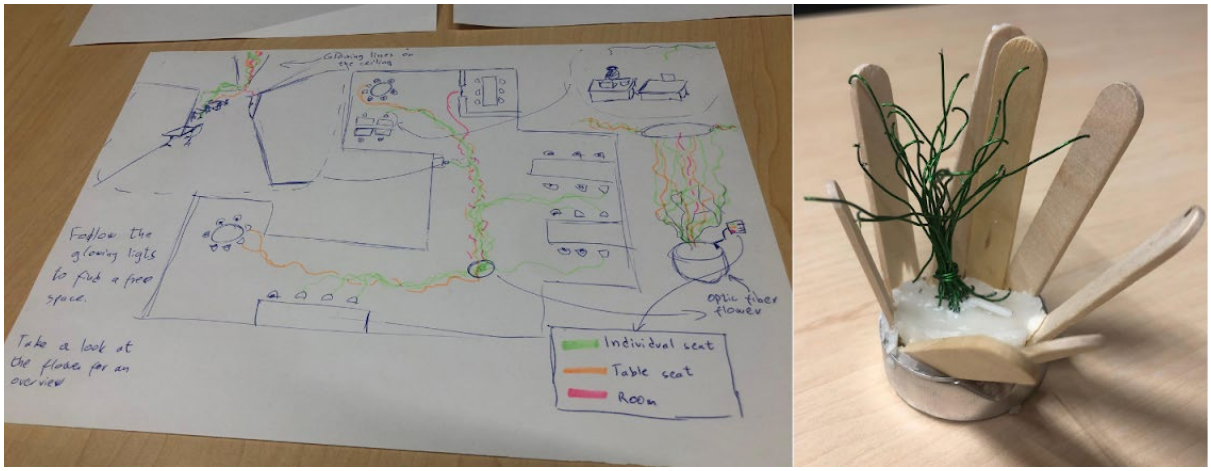

Figure 32. Fibre Optic Flower: left) the drawing explains the overall system showing a view of the map of the library with coloured fibre optic cables running from the plant on the right side across the ceiling towards available study places, right) a low-fidelity prototype of the fibre optic plant created with metal wires to indicate the cables pressed in a tea light to be kept into place.

Idea 23: Miniature Campus Map

A desk-sized object idea that was proposed includes a detailed miniature 3D map of the entire campus that can be displayed in each building entrance. This map showcases every campus building as a distinct, movable element, with its height varying to indicate occupancy levels. Specifically, a lower position represents minimal occupancy, while a higher position indicates greater occupancy. Uniquely, each building would have a 3D map designed to reflect the character of its respective department. For example, in the Engineering faculty building, the map elements could resemble components on a circuit board, with each representing a different building. Similarly, for the Medical faculty, the elements could be styled to reflect health and medicine themes. Users can easily view this map to understand the occupancy levels across multiple campus buildings at once.

Idea 24: Birdsong system

The following idea uses sound to convey the occupancy data of the library. In this idea, speakers are installed in the boulevard, which is the outside area next to the library building. These speakers will play distinct bird songs, each correlating with different occupancy rates within the library. Over time, this setup aims to foster a subconscious association among users, linking the type of bird song to the availability of space in the library. This concept offers an unobtrusive method of translating occupancy data, easily integrated into the outdoor environment of the library. Users can interpret the crowdedness of the library simply by listening to the bird songs as they pass by or spend time in the boulevard area.

Idea 25: Inflatable dolls

Another concept that was ideated upon with the idea to be placed in the boulevard area features an arrangement of inflatable car wash-style dolls, each representing a different building on campus. These dolls are designed to inflate or deflate in response to the occupancy levels of their corresponding buildings. For a building with low occupancy, its respective doll will be fully inflated, visually inviting students to visit this less crowded space (see Figure 33). Contrastingly, a building with high occupancy will have its doll less inflated, demonstrating the crowdedness in the building. This physicalization offers a dynamic and easily interpretable visual for students to assess the occupancy of various campus buildings at a glance.

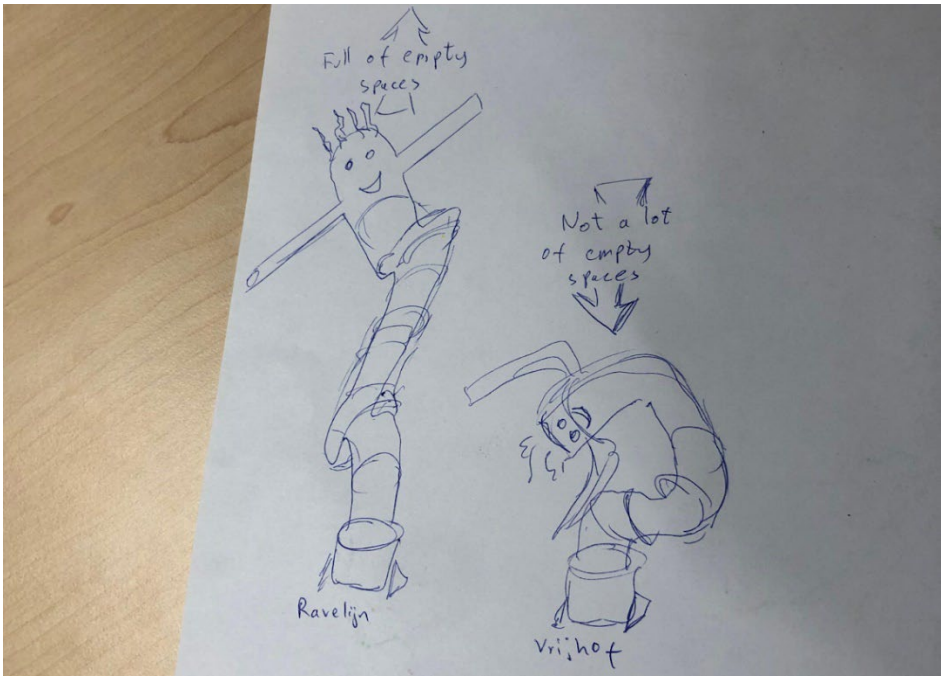

Figure 33. Inflatable Dolls: a drawing of the concept showing an inflated doll for the Ravelijn building indicating low occupancy and a deflated doll for the Vrijhof building indicating crowdedness.

Idea 26: Coffee taste

A concept that was proposed utilises gustatory feedback as a means to communicate the occupancy levels of the university library. It involves altering the taste of coffee dispensed from the machines within the university library. The system adjusts the bitterness of the coffee based on real-time occupancy data. As the library reaches higher occupancy levels, the coffee dispensed from the machines incrementally increases in bitterness. The shift is intended as a nudge for visitors to consider moving towards less crowded spaces on campus. Conversely, during periods of lower occupancy, the coffee remains less bitter. This application provides library visitors with an implicit signal about the current level of occupancy through the taste of their coffee.

5.3.2 Analysis of data physicalization ideas

Building on the diverse range of design ideas generated during the two participatory design workshop session, the following sections will continue with a structural analysis of these physicalization concepts. Participants contributed a total of 26 ideas for the physicalization of occupancy data, described in Section 5.3.1 and summarized in Table 4. As described in Chapter 3, the analysis involves a mixed-method approach by integrating structural coding with reflexive thematic analysis to explore the dimensions of the design space for physicalizations of library occupancy data. To perform this analysis, the next section involves a process of tagging the design descriptions to identify emerging themes and possible dimensions. Afterwards, the applicability of dimensions from established design spaces for data physicalizations was evaluated for the 26 design ideas. Additionally, a comparison between the emerged dimensions from the first analysis phase and these established dimensions was made. Lastly, the resulting dimensions from this process were further refined to create and define the final design space.

Table 4. Summary of the data physicalization design ideas for library occupancy data created in the participatory design workshops.

ID	Name	Short description
I1	Colour-changing keychain	Keychain with a liquid chemical that changes colours to indicate library occupancy levels.
I2	Vibration keychain	A keychain that vibrates with varying intensity and duration to indicate library occupancy levels.
I3	Thermal keychain	A keychain that changes temperature based on library occupancy levels.
I4	Sound keychain	A keychain with soundboard technology, emitting sounds reflecting occupancy in different library areas.
I5	Light keychain	A traffic light-inspired keychain using a colour spectrum to indicate library occupancy.
I6	Library map card	A card showing a map of the library with illuminated areas representing occupancy levels.
I7	AR smartwatch	A smartwatch projecting a 3D digital twin of the library using AR to display occupancy levels.
I8	Responsive jacket	A jacket that contracts or expands based on the occupancy of the library, simulating crowdedness.
I9	Elevating library map	A desk-sized 3D map of the library with elevations representing occupancy levels in different sections.
I10	Miniature building	A miniature library building model displaying occupancy through lights in various areas.
I11	Responsive sculpture	An art sculpture that expands or contracts based on library occupancy.
I12	Responsive plant	A plant-like structure with integrated LEDs that grows or diminishes in size to reflect occupancy levels.
I13	Adaptive painting	A digital painting changing style according to library occupancy levels.
I14	Ambient music	Music that changes in volume and style to reflect the library's occupancy.
I15	Overhead light indicator	A lighting system indicating noise levels and seat availability in the library.
I16	Candle display	A desk-size display with electric candles representing occupancy of library project rooms.
I17	Library fountain	A fountain adjusting water flow to represent library occupancy.
I18	LED map	A wall-mounted library map with LEDs showing the occupancy status of library spaces and seats.
I19	Footprint projection	A projection system displaying visitor footprints on the floor to indicate library occupancy.
I20	Magnetic art piece	An art installation using metal balls and magnets to display occupancy numbers.
I21	Interactive animatronic	An animatronic providing occupancy data and responding to movement or speech.
I22	Fibre optic flower	A fibre optic cable system with a central 'flower' indicating the availability of specific library seats and rooms.
I23	Miniature campus map	A 3D map of the campus with movable elements indicating occupancy in different buildings.
I24	Birdsong system	Speakers playing bird songs that correlate with library occupancy levels.
I25	Inflatable dolls	Inflatable dolls representing different buildings, inflating, or deflating based on building occupancy levels.
I26	Coffee taste	A system adjusting the bitterness of coffee dispensed based on library occupancy levels.

5.3.3 Identification of broader patterns

This section presents the process of the initial tagging of the data to provide an understanding of the variety of dimensions inherent to the design of the proposed physicalization ideas. The raw, tagged data be found in Appendix G.

The orange tag describes the general idea or concept behind each design, which highlights the need for a dimension that explains the physical form associated with the data physicalization. This dimension should encompass or point to the type and size of the device and inform the potential application areas. Looking at the gathered data physicalization ideas, the dimension could range from known or relatable items, such as 'keychain' or 'card', to more unclear or abstract descriptions, such as 'desk-sized object' or 'art installation'. Moreover, concepts like I14 (ambient music), I24 (birdsong system), and I26 (coffee taste), suggest a broader scope of physicalization that can encompass sensory experiences, but are not exclusively confined to tangible objects. However, this also implies that the form associated with the data physicalization is along the lines of 'integrated systems', for example I14 (ambient music) and I24 (birdsong system) could be defined as 'sound systems.' Therefore, this dimension should encapsulate the diverse forms and types of devices and systems that encompass data physicalizations.

The yellow tag focuses on the kind of data being translated and presented in the data physicalization, which points to a dimension centred around the type of data. By looking at the various designs, both widespread and distinct data types related to the university library and occupancy clearly arise. One of the data types that often reoccurred is 'library occupancy', which refers to the number of people present inside the library compared to its total capacity. Other types include more specific data such as 'occupancy levels of specific areas within the library', 'seat availability', and 'project room availability'. Some designs integrate data types that involve a form of sensing other than occupancy levels, such as 'noise data' in I15 (overhead light indicator), or include an extended occupancy sensing range, such as 'campus building occupancy' in I23 (miniature campus map) and I25 (inflatable dolls). Furthermore, various designs demonstrate data physicalizations that can show multiple data types or allow the user to select specific data types to be presented. Therefore, this dimension should cover a wide range of data types and allow for multiple types at once.

The green tag delves into the specific technologies and components integrated in each design, which points to the user interaction and the physical structure of the system. This tag relates somewhat closely to the orange tag, providing a more detailed and technical description of its physical form. This tag includes components like 'small electric candles', 'liquid chemical', or 'LEDs', and references to physical forms, such as the 'plant-like structure' of I12 (responsive plant), the 'miniature version of the library building' of I10, and the description of the cable system of I22 (fibre optic flower). The description of I19 (footprint projection), 'footprints remain visible as long as the individual is inside the building and disappear once they exit', illustrates how some designs provide detailed information about their functionality. This tag suggests the need of a data physicalization dimension that describes the specific technologies used and a brief explanation of how they work.

The pink tag addresses the way in which data changes appear within the physicalization and how this is conveyed to the user, referring to the output of the system and the sensing channel it uses to provide feedback. Numerous designs for data physicalizations utilise visual indicators for data representation. For instance, I1 (colour-changing keychain), I6 (library map card), I16 (candle display), and I22 (fibre optic flower) all use light and colour indications to demonstrate a change in occupancy levels of the library. Alternatively, I19 (footprint projection) uses the density of footprints to signify library occupancy levels. I25 also uses a visual cue, but in the shape of height and movement of an

object rather than light or colour. A visual indication that differs from light and colour indications is demonstrated by I9 (elevating library map) and I25 (inflatable dolls) that utilise height changes to convey changes in library occupancy data. Other sensory methods of data representation include but are not limited to vibrational feedback (I2 vibration keychain), thermal feedback (I3 thermal keychain), auditory feedback (I4 sound keychain, I14 ambient music, and I24 birdsong system), pressure (I8 responsive jacket), and gustatory cues (I26 coffee taste). This tag highlights the need of a dimension indicating methodologies used to convey data to users.

The blue tag represents the relation between data type (yellow tag) and its presentation (pink tag) through specifying the specific data mapping mechanism of the data physicalization design. For example, I5 (light keychain) uses a colour spectrum to associate specific colours with various levels of library occupancy. Another type of mapping is shown by, among others, I8 (responsive jacket) that directly maps each increase in occupancy level with its pressure output. Contrastingly, I22 (fibre optic flower) shows a more binary mapping: a light turns on if a particular library seat is available and off when occupied. Although, despite its binary mapping nature, the optic flower itself provides users an indication of the overall occupancy level at the library. I25 (inflatable dolls) shows a multifaceted mapping approach where each doll represents a specific building and maps its corresponding occupancy level through the level of air in the dolls, making them taller and move more. Consequently, this tag demonstrates the need for a dimension that encompasses a diverse range of data mapping methods and allows for multiple data mapping points.

Lastly, the brown tag focuses on practicality, placement, utility, and interaction aspects of each design. The shape, size, and placement of the data physicalization all vary largely among the different design ideas, ranging from personal, user-specific items to large-scale installations that are seamlessly integrated into the environment, like the birdsong system of I24. Additionally, this tag describes the level and nature of interaction (conscious or subconscious) and indicates when and where data is accessed by the user. It also reveals the type of audience the data physicalization is designed for, varying from individual device owners (e.g. ideas I1-I8) to broader installations that are placed in communal university spaces (e.g. ideas I9-I26). The tag indicates the need for one or more dimensions that indicate the interaction modalities, placement, and integration, and intended audience.

5.3.4 Emerging dimensions

The initial identification of broader patterns in the generated designs for data physicalizations of library occupancy data has resulted in a variety of possible dimensions. As mentioned above, there are several tags that indicate the need of a specific dimension. The following possible dimensions can be identified and formulated from the initial analysis of tagged data:

- *Form and type*: focuses on the physical and conceptual form of the data physicalization device or system.
- *Data type*: indicates the data type that the physicalization represents.
- *Technology and components*: describes the specific technology and components used in the data physicalization.
- *Sensory output*: demonstrates the methods used to convey data changes to users.
- *Data mapping*: involves the precise data translation from data input to data output.
- *Placement and integration*: focuses on the intended placement and integration of the physicalization in the environment.
- *Audience*: indicates the audience for which the data physicalization is designed.

- *Interaction and utility*: addresses the interaction methods of the data physicalization from the perspective of the user.

Another aspect that came to light from the analysis, but that was not initially apparent from the tagged descriptions, relates to the timelines for implementing specific designs. This aspect, which can be described as '*Temporal design scope'*, identifies when each design solution might be realised and integrated, considering three different time periods: the immediate, near, and far future. For instance, considering the current sensor infrastructure within the library, designs for the immediate future involve using data that is already being obtained. These designs focus on the current state of data collection and do not need major changes to the existing space to be installed. For the near future, designs may need other data types, requiring a more sophisticated sensor infrastructure. These data physicalizations may take more time to develop and implement. Lastly, designs for the far future are the most ambitious and might seem futuristic. These designs often require significant changes to the space they would be installed in and are not easy to set up. In a sense, the *Temporal design scope* dimension is about when a design realistically could be realised, ranging from simple devices to more complex installations.

5.3.5 Comparison and evaluation of existing dimensions

In the second part of the analysis, the extracted dimensions are compared with established dimensions from existing literature. A summary of established design dimensions is provided by [56] as shown in Table 5. This table summarises the analysis of the design dimensions of design spaces and frameworks from 11 papers focused on data physicalizations. Each of these established dimensions will be analysed and evaluated for their applicability in categorizing the physicalization concepts for library occupancy data.

Table 5. (Table 1 from [56]) Summary of design dimensions from established design spaces for data physicalization.

	Design Dimensions													
Design Space/Framework	Data	Audience	Representational Intent	Representational Material	Sensory Modalities	Encoding Variables	Representational Fidelity	Interaction	Proximity—Data Ref.	Proximity—User	Physical Setup	Mobility	Narrative Formulation	Evaluation
Mutisensory Design Space [57]					x	x								
Data Sculpture Domain Model [58]			x											
Embodiment Model [58]							x							
Data Sculpture Design Taxonomy [59]							x						x	
Framework for Situated and Embedded Data Representations [33]									x					
Framework for Multisensory Data Representation [60]	x		x	x	x									
Framework for Multisensorial Immersive Analytics [61]	x		x		x	x					x			
Physecology [62]	x					x		x		x	x			
Cross-Disciplinary Design Space [63]	x	x	x	x	x	x		x		x		x		
Design Elements in Data Physicalisation [64]	x		x	x	x	x	x	x						
Encoding Variables and Evaluation of Data Physicalizations [56]						x								x
N	5	1	5	3	5	6	3	4	1	2	2	1	1	1

Data

Data describes the way in which information is represented and communicated with the physicalization [56, p. 3]. Although this dimension is part of multiple design spaces and frameworks, as shown in Table 5, the description of this dimension is not always similar. For instance, [60] suggests that data in physicalization can be classified into two main categories: archived (static) data and live (dynamic) data. This is in accordance with [62] that integrates the *data availability* dimension classifying datasets as either static or dynamic. However, this classification is less relevant for data physicalization designs of library occupancy as the data is inherently dynamic as it is obtained and presented in real-time.

Furthermore, [62] integrates *data attributes* and *data topic* as other data dimensions in their design space. According to [62] and [61], the *data attributes* dimension classifies datasets as either categorical or nominal data (which differentiates data points as similar or different), ordinal data (which shows a clear order but lacks direct mathematical comparability), or quantitative data (which involves measurement and supports mathematical comparison). Although the type of database is dependent on the library or university's ability to gather specific data, the way these data points are used varies across the different physicalization designs. For example, I5 (light keychain) and I24 (birdsong system) show categorical data, while I8 (responsive jacket) and I26 (coffee taste) utilise ordinal data and I19 (footprint projection) uses quantitative data. Additionally, certain designs incorporate multiple types of data attributes. For instance, I14 (ambient music) uses both categorical and ordinal data to convey library occupancy levels. It categorises occupancy through different music styles and uses ordinal data by adjusting the volume of the music to reflect the occupancy level. Therefore, a dimension specifying the data attribute seems to be applicable for categorization of physicalizations of library occupancy data.

The *data topic* dimensions as mentioned by [62] refers to a certain category to which the presented data can belong and is similarly proposed by [61], [63], and [64]. The options within this dimension focus on the topic or theme of the data, rather than its specific type. Examples of these options include, among others, tabular data, and textual datasets [61], biological, environmental, image/video data [63], as well as academics, history [64], personal data, and geospatial data [62]. From the first analysis phase of the physicalizations of library occupancy data, the *data type* dimension was identified. While this dimension seems similar to those in established design spaces and frameworks, the options provided by these existing design spaces and frameworks appear too broad for the specific, diverse range of occupancy-related data for the library and university campus. For instance, the design ideas for library occupancy data physicalizations include specific data types such as library occupancy levels and project room availability. This suggests that, although a dimension for specifying the data topic exists, it needs a more refined and precise classification, different from existing dimensions regarding the type of data. This refined dimension should be tailored to address the different aspects of data relevant to both the library and the university campus.

Audience

Audience refers to the type of the target audience [56, p. 3]. This dimension was identified by [63] that defines the audience as the intended recipients of a physicalization, such as the general public, researchers, or children. In the context of physicalizations of library occupancy data, the audience is explicitly the regular users of the library and other university visitors, making the broad audience options mentioned in [63] less relevant here.

Interestingly, [62] explores the audience dimension from the perspective of "physecologies," a term they use to describe physical data representations. In their analysis, they identify users and spectators as the two primary audience types. The research categorises physecologies based on their

contextual audience reach differentiating between private, semi-public, and public physecologies. Private physecologies are designed for individual or household use, with occasional spectators such as visiting friends, and are likely to represent personal data. In the case of physicalizations of library occupancy data the data is inherently not personal and seemingly private physicalization like I8 (responsive jacket) and I3 (thermal keychain) are only comprehensible or experiential by the wearer or holder. Semi-public physecologies are aimed at specific communities and are likely to represent personal or community data. By looking at the physicalization designs of library occupancy data, there are many examples that would be considered as designed for a semi-public audience when they are not meant for "private" use. Lastly, [62] considers public physecologies as the third category in the audience dimensions. This category is not applicable to this research project, as the data is specifically meant for the university community.

Although the *audience* dimension was identified in the first phase of the analysis of the physicalization designs of occupancy data, it is clear that the audience categorization from [63] does not fit in this context and the description as provided by [62] is more applicable. However, a more nuanced classification could make this dimension more tailored to the design space by identifying private, personal, and semi-public physicalizations. This allows for differentiating between physicalizations that are observable by bystanders (private) and those that are exclusively meant to be experienced by individuals using them (personal). For instance, I8 (responsive jacket) and I3 (thermal keychain) are personal physicalizations, experienced solely by the user, whereas I1 (colour-changing keychain) and I6 (library map car) are private, observable, and interpretable by others.

Representational intent

Representational intent addresses the underlying purpose behind the data physicalization audience [56, p. 3]. Despite its integration in multiple design frameworks, the interpretation of this dimension varies across studies. [63] introduces the *Task* dimension to indicate the goal of the physicalization, categorising its purpose into tasks such as 'analyse', 'educate', or 'express'. Alternatively, [61] offers a more in-depth indication of *representational intent* through expanding this classification by distinguishing between high-level and medium-level tasks. A different approach is shown by [64], that categorises the *design purpose* of artefacts according to their function and audience, with options such as 'public informing tools' and 'research aids'. Additionally, they note that a single physicalization can serve multiple functions based on its application. Contrastingly, [58] approaches the classification on a spectrum from 'artistic expression' to 'functional utility', offering a perspective on the balance between artistic and utilitarian aspects. Similarly, [60] divides the *intent* dimension into 'utilitarian' for specific tasks and 'casual' for more open-ended engagement.

By analysing the designs of physicalizations of library occupancy data, a utilitarian intent emerges as their purpose is primarily focused on informing the audience. This focus inherently stems from the context of the physicalization, as the designs were developed following a predetermined objective of conveying data to inform students. Therefore, the broader classifications from the aforementioned studies seem less applicable in this context. Although artistic elements are identifiable in the physicalization designs, incorporating this classification on a scale with a utilitarian focus, as [58] does, may not be necessary. A more effective approach could be to address artistic or aesthetic elements as a separate dimension. This would allow for a clearer categorization of the physicalizations based solely on their artistic aspect, rather than combining it with the shared utilitarian characteristic.

Representational material

Representational material refers to the material used for the physicalization audience [56, p. 3]. [64] identifies the materials used in physicalizations as larger thematic groups, such as plastic, fluids, and fabric. This is in line with the classification as described by [60], that identifies the *materials or medium* of every physicalization in similar groups although more extensive than [64] by including materials that can be sensed by different channels such as bread, infrared light, and MIDI electronic motors. Contrastingly, [63] categorises the *material* of physicalizations in two general groups: electronic or non-electronic. It categorises physicalizations as electronic if any components are used to control the flow of current, whereas physicalizations are classified as non-electronic when there are no computational abilities.

In the context of data physicalizations of library occupancy, given that the information of the data physicalization needs to be updated to keep the output compliant with the real-time data delivery requirement, following the classification as described by [63], physicalizations would always be classified as electronic if the classification indicating no distinction between the designs. The categorization as described by [64] and [60] seems the most appropriate. However, similar to [64], the dimension should allow for materials and mediums that can be sensed by sensory channels other than visual or haptic, such as coffee for I26 (coffee taste).

Sensory modalities

Sensory modalities refer to the human sensory channels used to perceive data in physicalizations [56, p. 3]. [57] outlines a classification of this dimension for the multi-sensory design space, distinguishing sight, sound, and touch as key sensory channels used for data presentation. A slight difference is presented in the dimension description of [63], that recognizes four *sensory modalities* including visual, tactile, aural, and taste. Expanding this categorization, both [60] and [61] also include smell as a possible sensory modality. Moreover, [61] highlights the combination of modalities that physicalizations can utilise to present data, such as combining touch with sight. Interestingly, [64] introduces kinaesthetic experience as an additional sensory modality.

The descriptions and classifications of this dimension as described by [60], [61], and [64] seem to align with the *Sensory output* dimension identified in the initial analysis phase for library occupancy data physicalizations. Furthermore, the idea of combining sensory modalities, as suggested by [61] and [23], is also applicable in this case as some physicalization designs exhibit multiple sensory modalities.

Encoding variables

Encoding variables describes the physical variables that are used in physicalizations to encode data [56, p. 3]. The analysis in [56] explores a wide variety of design spaces and frameworks, composing a detailed synthesis of the classification of this dimension. The identified variable types include physical, visual, haptic, sonic, olfactory, gustatory, and dynamic variables. Within these categories lie several options, such as slipperiness, visual arrangement, and friction.

This classification seems relevant for the physicalizations designs of library occupancy data, as it integrates an inclusive and diverse range of options. For example, I8 (responsive jacket) uses the haptic variable of pressure to represent library occupancy levels, while I19 (footprint projection) makes use of the visual variable of numerousness for its data encoding.

Representational fidelity

Representational fidelity refers to the metaphorical relationship between the presented data and the materials used for its encoding in physicalizations, identifying to which extent data is embodied in the physical representation [56, p. 3]. Across various design spaces and frameworks, this dimension seems to be interpreted consistently with slight variations.

[58] introduces a conceptual model for data sculpture embodiment that focuses on the metaphorical distance between the presented data and reality. Similar to [59], it identifies three primary types of relationships: symbolic, indexical, and iconic. Iconic relationships involve data representations with a close metaphorical distance to reality by providing a direct physical or causal link, while symbolic representations have the most abstract, distance link to reality. Indexical relationships lie exactly in between symbolic and iconic. [64] complements this description by categorising data sculptures from a design aesthetic perspective, ranging from abstract to literal metaphors. This approach aligns with the symbolic-indexical-iconic range of [58] and [59].

In essence, all three studies identify the *representation fidelity* dimension as a range from abstract to literal physicalizations. In the case of the various designs of library occupancy data physicalizations, it seems possible and applicable to classify them along this classification.

Interaction

Interaction addresses the type and nature of user interactions with the physicalization [56, p. 3]. [60] distinguishes the *interaction* element of data physicalizations through passive and active interaction modes, referring to the ability of the user to control the data representation. For library occupancy physicalizations, this distinction is somewhat too nuanced. Most designs that offer a form of direct interaction, such as I2 (vibration keychain) and I4 (sound keychain), do not allow for extensive active interaction but rather a simple activation mechanism such as a button. This interaction is primarily used to activate the physicalization instead of controlling other elements shown by the data presentation.

[62] introduces a hierarchical categorization with the *Interaction Directness* dimension to categorise physicalization interactions as direct, indirect, and non-interactive, and further detailing the nature of interaction as manipulation, exploration, or configuration with the *Interaction Implications* dimension. However, this more detailed framework seems to identify library occupancy designs on a singular outcome, which mostly fall into the non-interactive category, limiting its applicability.

Contrastingly, [63] focuses on the mechanisms capturing the data interactions, such as sensors or direct actions, which is more aligned with the device-centric aspects of interaction. In terms of activating the physicalization, in the context of the designs for library occupancy data this distinction may be applicable. Where the installation could be directly activated through pressing a button or by sensing movement of the user.

Lastly, [64] differentiates between *audience sensory interaction* and *artefact interactivity*. However, the *audience sensory interaction* dimension fits more in the context of sensory modality, focused on the mediums through which the data is conveyed to the user. The *artefact interactivity* dimension identifies the actuation form that is used to support interaction, which include change in shape or form, change in colour, and change in position in space as actuations, and non-interactive/static physicalizations. Although most library occupancy physicalizations predominantly fall into the non-interactive/static category as they do not usually allow for significant change or manipulation. While the interaction might not vary widely across designs for the data physicalization designs of library

occupancy, there are still subtle differences noticeable. For instance, some designs require user activation to display data, such as in I2 (vibration keychain) and I4 (sound keychain).

A unique aspect in the context of library occupancy data, is how users can indirectly interact with the physicalization by changing a data point by occupying a space in the library. Yet, this indirect interaction remains consistent across all designs. A design that particularly stands out is I24 (birdsong system), which conveys the data in a subconscious manner, which differs significantly from the other more direct interaction forms. This, however, may be addressed by other dimensions such as *Proximity to the user*. In conclusion, although with a different range of options than proposed by established physicalization design spaces, the *Interaction* dimension seems to be applicable in this context.

Proximity to the data referent

Proximity to the data referent refers to the degree of integration and contextual relationship between a data physicalization and its associated data or physical referent [56, p. 3]. This dimension is explained by [33], who proposes a range for the categorization from non-situated to situated. At one end, non-situated data representations lack the spatial or physical connection to the data it refers to, while situated representations are designed to be in proximity to their physical referents.

In the case of physicalization designs of library occupancy data this categorization seems to be applicable. For example, I2 (vibration keychain) is a non-situated physicalization, as it is a portable device that does not inherently relate to a specific physical location, such as the library or the university. I17 (library fountain) and I19 (footprint projection) are examples of situated physicalizations. As they are designed to be positioned at the library entrance, they enable visitors to relate the presented data with the library environment, although viewers may still need to actively draw connections between the data and its physical referent. Physicalizations that take situatedness a step further are embedded representations. Apart from conveying data in proximity to its referents, these data physicalizations are spatially and contextually integrated in the physical environment. An example of this is I22 (fibre optic flower), which displays the occupancy of specific library seats through fibre optics cables on the ceiling, seamlessly connecting the entrance to available spots in the library.

The established dimension as proposed by [33] seems to fit well for classifying data physicalizations of library occupancy based on their proximity to their data referents.

Proximity to the user

Proximity to the user focuses on the degree of embodiment and situatedness of the physicalization in relation to the user or their environment [56, p. 3]. [63] addresses this dimension by differentiating between technology-driven and contextually driven embodiments. Technology-driven physicalizations use platforms where technology is leveraged to encode data, while contextually driven physicalizations represent data through people, environments, or activities. However, this approach primarily categorises the type of embodiment rather than detailing the degree of proximity to the user.

In contrast, [62] approaches this dimension by exploring spatial coupling to understand the spatial relationship between the user and the physicalization. This framework categorises spatial coupling into four layers: full, nearby, environmental, and distant, with an additional option of no coupling. Full coupling allows for direct interaction with the physicalization, while nearby coupling involves explicit, indirect interactions close to the physicalization. Environmental coupling refers to situations where the output is in the environment surrounding the user. Finally, distant coupling describes outputs of data physicalizations that occur remotely, both spatially and temporally. This framework highlights the various degrees of spatial relationship between the user and the

physicalization. This classification of *spatial coupling* seems more appropriate and applicable in the context of data physicalizations of library occupancy compared to the framework as proposed by [63]. It integrates various levels of proximity that can be identified in the different physicalization designs. For instance, I24 (birdsong system) represents an environment coupling, as the sound output surrounds the user in its environment, whereas I22 (fibre optic flower) shows a nearby to full coupling, as it offers direct manipulation at a specific library seat and influences at the same time the data output at the flower display at the entrance of the library.

Physical setup

Physical setup details the arrangement and distribution of components of a data physicalization [56, p. 3]. This concept is particularly useful for defining and understanding the functionality and interaction dynamics of the physicalization [62]. [61] identifies a variety of hardware setups for data visualisation, ranging from large collaborative spaces to personal displays, and immersive technologies like head-mounted displays for virtual reality. While these classifications offer valuable insights in this dimension, they may not align with the characteristics of physicalizations designed for library occupancy data.

Introducing a more generalised classification framework for the dimension of *physical setups*, [62] categorises data physicalizations into standalone physicalizations, physecologies with spatial distribution, and physecologies with logical distribution. Standalone and spatial distribution physicalizations typically represent static data, while logical distribution physicalizations often represent dynamic datasets. In the context of library occupancy data, the dynamic nature of real-time data presentation automatically identifies all proposed designs as a logical distribution physicalization. Due to the real-time data requirement, the physical setup needs to facilitate active communication and response between sensors and physical components. As a result, the classification provided seems limited for this specific context. As it primarily points towards logical distribution as the fitting option, it does not fully capture the diversity and potential of different physicalization designs. A more nuanced or expanded classification for this dimension might better fit the designs of library occupancy data physicalizations.

Mobility

Mobility identifies whether physicalizations are confined to a specific location or not [56, p. 3]. As explained by [63], physicalizations can be categorised based on their mobility as either bounded or unbounded to a location. Although [63] does not explicitly focus on this in their classification, similarly to [33], they address the concept of situatedness of data physicalizations. This concept relates to how the information displayed by a physicalization is contextually relevant in its environment. Interestingly, [63] expands the traditional understanding of situatedness by introducing the idea of body-embedded, situated physicalizations. These are physicalizations that are not confined to a specific location and often convey personal data.

In the context of representing library occupancy data, the concept of embeddedness inherently implies a location-bound design, as the library is a fixed, static location. However, several proposed design ideas (i.e. I1-I8) can be identified as mobile or unbound data physicalizations. While other physicalization designs for library occupancy data could theoretically be moved due to their portable components, they are not typically intended for mobile use. This distinction indicates that a dimension with a focus on mobility, especially in combination with a dimension regarding the situatedness of a physicalization, seems to fit well in the context of data physicalizations of library occupancy data.

Narrative formulation

Narrative formulation describes how discovering and understanding information is facilitated by data physicalizations through their physical form and interactive aspects [56, p. 3]. [59] describes three categories that can be distinguished in this dimension: physical properties and affordances, interaction, and play. Physicalizations that create a narrative through physical properties and affordances utilize their form and sensory attributes to enable a passive interpretation of data. Contrastingly, physicalizations creating narrative through interaction encourage active engagement by hands-on exploration and understanding of the data. Lastly, the category of play involves physicalizations that incorporate playful elements into their design. This approach aims to reveal insights and patterns in the data through engaging and playful interactions.

In the context of physicalizations designed for library occupancy data, some designs, such as I25 (inflatable dolls), demonstrate some aesthetically playful features. However, many designs focus on explaining the data intuitively without requiring extensive user engagement. Designs like I2 (vibration keychain) show simple interactions, enabling users to activate data by pressing a button. While there is potential for more interactive and playful designs, considering the specific context and objectives of library occupancy data, more complex narrative formulations may be less relevant.

Evaluation

Evaluation refers to methods used to assess the impact of data physicalizations [56, p. 3]. According to [56], this dimension involves both the criteria for evaluation and the methods utilised in the assessment process. [56] mentions that systematic evaluation typically occurs in the final phase of creating and implementing a data physicalization, often as part of the research rather than during the design phase.

In the specific case of the physicalizations designed to present library occupancy data, there appears to be little to no reference to established evaluation criteria or methods. However, insights from [56] could guide future research and design practice in assessing the effectiveness of these physicalizations. The study also investigated the relationship between evaluation criteria and the intent of the physicalization (utilitarian or casual).

In the case of library occupancy data, physicalizations tend to be primarily utilitarian and aim to inform users about real-time occupancy. Possible evaluation criteria could include for example utility, effectiveness, or orientation consistency [56, p. 15]. These criteria can then inform the selection of an appropriate evaluation method. However, within the scope of this research project, the *evaluation* dimension may not be a primary concern at this stage of development. However, future iterations of the project could incorporate these evaluation aspects in the design space.

5.3.6 Final dimensions

After an in-depth analysis comparing the established dimensions with those that emerged from the first phase, a refined set of dimensions for data physicalizations designed in the context of library occupancy data can be defined. This refinement process led to the integration and redefinition of some emerging dimensions, and the introduction of the A*esthetics* and *Temporal design scope* dimensions.

Specifically, the *Form and type* dimension has been replaced by the broader *Physical setup* dimension. The *Data type* dimension has been expanded to include the *Data attribute* dimension to offer a more detailed understanding of the presented data. The dimension of *Technology and components* is now partially encapsulated by *Representational material*. While this dimension does not explicitly define the components of the physicalization, it is important to note that these physicalizations

are currently only conceptual. Actual implementation may differ in their technical specifics, which makes a focus on the representational material solely sufficient for now.

The *Sensory output* and *Data mapping* dimensions are now represented by *Sensory modality* and *Encoding variables*. The *Encoding variables* dimension provides a general overview of which methods are used to indicate changes in the presented data, as opposed to the specific translation of the variables in the *Data mapping* dimension.

The *Placement and integration* dimension is replaced by the *Proximity to the data referent* and *Mobility* dimensions that combined address where and how the physicalization fits within its environment. Finally, the *Interaction and utility* dimension has been divided into separate ones including the *Interaction, Mobility*, and *Proximity to the user* dimensions, each focusing on different aspects of user engagement and interaction with the data physicalization.

The final dimensions for the design space include:

- **Data type**: indicates the thematic focus of the data the physicalization represents. *Options include: Library occupancy, Specific library occupancy, Seat availability, Seat reservation status, Project room availability, Campus-wide occupancy, Noise data*
- **Data attribute**: classifies the data presented by the physicalization based on its nature. *Options include: Categorical data, Ordinal data, Quantitative data*
- **Representational material**: refers to the substance or medium used to present data in the physicalization. *Options include: LEDs, Audio output, Coffee, Synthetic materials, Mechanical components, Metal, Water, Candles, Light display, Magnets, Projected light, Chemical liquid, Thermally conductive material, Augmented reality, Smart fabric, Light display, Expandable material, Fibre optic cables, Air system*
- **Sensory modality**: refers to the human sensory channels used to perceive data in the physicalization. *Options include: Visual, Tactile, Aural, Taste, Smell, Kinaesthetic*
- **Encoding variables**: describes the physical variables in physicalizations that are used to encode data. *Options include; Physical variables, Visual variables, Haptic variables, Sonic variables, Olfactory variables, Gustatory variables, Dynamic variables*
- **Representational fidelity**: examines the metaphorical distance between the data and its physical representation. *Options include: Symbolic, Indexical, Iconic*
- **Audience**: identifies the target users of the physicalization. *Options include: Personal, Private, Semi-public*
- **Interaction**: addresses the nature and extent of user interaction with the physicalization. *Options include: Passive interaction, Active interaction, Subconscious interaction*
- **Proximity to the data referent** defines the spatial and contextual connection between the physicalization and its associated data. *Options include: Non-situated, Situated, Embedded*
- **Proximity to the user**: focuses on the degree of situatedness of the physicalization in relation to the user or their environment in terms of spatial coupling. *Options include: Full, Nearby, Environmental, Distant, No Coupling*
- **Physical setup**: details the type of physical components of the data physicalization. *Options include; Desk-sized object, Portable, Wearable, Wall-mounted object, Integrated installation, Non-physical installation, Other*
- **Mobility**: identifies whether physicalizations are confined to a specific location. *Options include: Bounded, Unbounded*
- **Aesthetics**: refers to the artistic elements of the physicalization. *Options include: Functional, Artistic, Thematic, Futuristic, Naturalistic, Playful, Musical, N/A*

- **Temporal design scope**: determines the expected timeframe for realising the physicalization. *Options include: Immediate future, Near future, Far future*

With these final dimensions, the design space can be used to classify each of the physicalization ideas created in the participatory design workshop. Table 6 and Table 7 present overviews of the classification of each of the 26 physicalization ideas. Insights in the design space and the specific design ideas are further discussed in Chapter 7.

Table 6. An overview of the 26 data physicalization design ideas categorised on data type, data attribute, sensory modality, encoding variables, audience, and interaction.

	Data type						Data attribute				Sensory modality					Encoding variables	Audience			Interaction		
	Library occupancy	Specific library occupancy	Seat availability	Seat reservation status	Project room availability	Noise data	Campus-wide occupancy	Categorical	Ordinal	Quantitative	Visual	Tactile	Aural	Kinesthetic	Taste		Personal	Private	Semi-public	Passive	Active	Subconscious
1 Colour-changing keychain	x							x			x					Colour hue		x		x		
2 Vibration keychain	x	x							x			x				Vibration amplitude, Duration	x				x	
3 Thermal keychain	x								x			x				Temperature	x			x		
4 Sound keychain		x						x	x				x			Loudness, Timbre		x			x	
5 Light keychain	x							x			x					Colour hue		x			x	
6 Library map card		x						x			x					Visual size, Colour value		x		x		
7 AR Smartwatch		x						x			x					Colour hue	x				x	
8 Responsive jacket	x								x			x		x		Pressure	x			x		
9 Elevating library map		x								x	x	x				Visual location, Tangible elevation			x	x		
10 Miniature library building		x						x			x					Colour value, Visual size			x	x		
11 Responsive sculpture	x								x		x					Visual shape, Visual size			x	x		
12 Responsive plant	x								x		x					Visual size, Rate of change			x	x		
13 Adaptive painting	x							x			x					Visual numerousness, Color hue			x	x		
14 Ambient music	x							x	x				x			Loudness, Timbre			x	x		
15 Overhead light indicator		x	x			x		x			x					Colour hue			x		x	
16 Candle display					x			x			x					Colour value			x	x		
17 Library fountain	x								x		x					Visual numerousness,			x	x		
18 LED map			x	x				x			x					Colour hue, Visual size			x	x		
19 Footprint projection	x									x	x					Visual location, Visual numerousness			x	x		
20 Magnetic art piece	x									x	x					Visual location, Visual shape			x	x		
21 Interactive animatronic	x						x	x			x		x			Change pattern			x		x	
22 Fiber optic flower			x		x			x			x					Colour hue			x		x	
23 Miniature campus map							x		x		x					Visual location, Tangible elevation			x	x		
24 Birdsong system	x							x					x			Pitch, Timbre			x			x
25 Inflatable dolls							x		x		x					Visual size, Change pattern			x	x		
26 Coffee taste	x								x						x	Taste type			x			x

Table 7. An overview of the 26 data physicalization design ideas categorised on representational fidelity, representational material, proximity to the data referent, proximity to the user, physical setup, mobility, aesthetics, temporal design scope.

	Representational fidelity				Representational material	Proximity to the data referent			Proximity to the user				Physical setup						Mobility		Aesthetics								Temporal design scope		
	Symbolic	Indexical	Iconic	Abstract		Non-situated	Situated	Embedded	Full	Nearby Environment	No coupling	Portable	Wearable	Desk-sized object	Integrated installation	Non-physical installation	Other	Bounded	Unbounded	Functional	Artistic	Thematic	Naturalistic	Futuristic	Playful	Musical	N/A	Immediate future	Near future	Far future
1 Colour-changing keychain	x				Chemical liquid	x					x	x							x	x								x		
2 Vibration keychain	x				Mechanical components	x			x			x							x	x								x		
3 Thermal keychain	x				Thermally conductive material	x					x	x							x	x								x		
4 Sound keychain	x				Audio output	x			x			x							x	x									x	
5 Light keychain	x				LEDs	x			x			x							x	x								x		
6 Library map card		x			LEDs	x					x	x							x	x										x
7 AR Smartwatch			x		Augmented reality	x			x				x						x					x						x
8 Responsive jacket		x			Smart fabric	x					x		x						x	x										x
9 Elevating library map		x			Mechanical components		x				x			x				x		x									x	
10 Miniature library building			x		Light display		x				x			x				x		x									x	
11 Responsive sculpture	x				Expandable material	x					x			x				x			x							x		
12 Responsive plant	x				LEDs, Synthetic materials	x					x			x				x					x						x		
13 Adaptive painting	x				Digital display	x					x						x	x			x								x	
14 Ambient music	x				Audio output	x				x						x		x							x			x		
15 Overhead light indicator				x	LEDs			x	x	x					x			x		x										x
16 Candle display				x	Candles		x				x			x				x			x								x	
17 Library fountain				x	Water		x				x			x				x			x							x		
18 LED map		x			LEDs		x				x						x	x		x										x
19 Footprint projection		x			Projected light		x				x				x			x		x								x		
20 Magnetic art piece	x				Metal, Magnets		x				x						x	x			x							x		
21 Interactive animatronic	x				Mechanical, Audio output	x				x				x				x		x				x					x	
22 Fiber optic flower	x				Fiber optic cables			x	x	x					x			x			x		x	x						x
23 Miniature campus map		x			Mechanical components	x					x			x				x				x							x	
24 Birdsong system	x				Audio output	x					x					x		x					x			x		x		
25 Inflatable dolls	x				Synthetic materials, Air system	x					x						x	x							x				x		
26 Coffee taste	x				Coffee		x				x					x		x								x			x		

6 Specification & realisation outline

This chapter presents a detailed specification and practical guide for the implementation of one physicalization design idea for communicating library occupancy data at the University of Twente. The chosen data physicalization design, fibre optic flower, is one of the ideas that emerged from the participatory design workshop (see Section 5.3.1, Idea 22: Fibre optic flower). This design has been chosen since it includes an embedded system, and its temporal design scope is in the far future. As this design is in close proximity to the data referent, it serves as an example of a data physicalization that has become a part of the environment itself through seamful integration, something that is often difficult to realise as (indoor) spaces would need to be remodelled. The deliberate choice was made to select a design with a futuristic outlook and realisation scope, as the aim was to showcase how future designs of buildings and indoor spaces could become more data-driven, focusing on empowering occupants by making building data more accessible. This example serves to inspire researchers and designers by providing a specific application scenario of physicalizing building data in a semi-public environment.

6.1 Design description

First, the original description of the physicalization design, as described in Section 5.3.1, will be shared. Then the requirements for a communication system of library occupancy data that were found with the results from the survey and focus groups will be evaluated, formulated, and used to modify the original description of the data physicalization.

6.1.1 Original design description: Fibre optic flower

This idea involves the integration of a fibre optic cable system within the library building. Central to this concept is a fibre optic ‘flower’ that is located at the entrance of the library building. From this flower, cables extend across the ceiling to various study areas and places within the library. The illumination of a fibre optic cable signifies that the corresponding space is available for use. Moreover, the colour of the cable indicates the type of space: green for individual seats, orange for table seats, and pink for project rooms. At the entrance, students can quickly assess the overall availability of spaces by observing the flower, where all the fibre optic cables come together. Afterwards, students can easily find and follow the specific-coloured cable on the ceiling to reach the specific type of study space. Additionally, every building with study spaces could feature a similar central display, surrounded by smaller flowers that indicate the real-time occupancy of other buildings on campus. This system provides a visual and intuitive method for students to navigate and find available study areas within the library and across the campus.

6.1.2 System requirements

The insights from the results of the library-wide survey and focus groups, as discussed in Chapter 4, will be used to formulate the requirements of the system. As this data physicalization is embedded in the indoor environment of the library building, it will address different needs of the users who are physically attending the space. This is important to point out, as students could use the real-time occupancy information and more comprehensive data (such as occupancy patterns and predicted occupancy levels) in their decision-making process in spaces other than the library. This specific system, however, is not designed to address these types of users and is solely focused on communicating relevant occupancy information to current library users.

One of the main user needs identified is that the occupancy information should not solely address the overall real-time library occupancy, but that it should be area specific. For instance, students

would like to know the occupancy within the silent area of the library or of the desks with monitors. Therefore, one of the requirements of the system is that it should present real-time, area-specific occupancy information. Moreover, there were suggestions given by the students for even more detailed types of library occupancy data they would be interested in, such as the occupancy of a seat next to the window or the availability of two or more seats adjacent to each other. A system that displays such detailed information is feasible, although it has the risk to cognitively overload users with the amount of presented data.

The system should be clear and easily understandable for users, yet it should not be distracting for people who are studying in the library. Its design should match the style and aesthetics of the library to integrate it well into the environment. The interface should be intuitive and present a clear user guidance, making it immediately usable even for those who are new to the library. Additionally, the system must include accessible features to be usable for all users, such as by implementing high-contrast visual elements to accommodate individuals with colour vision deficiencies.

From the perspective of the library and the university, considerations such as budget, energy consumption of the system, and adherence to privacy regulations are important elements for the system. Since this description involves the specification of a potential system that may be implemented in the future, the focus lies a bit less on the possible budget as it is difficult to predict what funding might be available and what the material costs will be. Still, the materials used for this system will be considered based on the current trends of prices and their costs will be balanced against their energy efficiency. Overall, the system should minimise energy consumption and incorporate privacy friendly design principles to ensure that any system breaches do not compromise the privacy of the users.

List of requirements

Through the analysis of both user and stakeholder needs, the specific requirements of the system can be identified and formulated. These requirements are categorised into functional requirements (FR), which focus on what the system must do, and non-functional requirements (NFR), which describe how the system must perform these tasks, as explained in Section 3.3.1. Additionally, these requirements have been prioritised following the MoSCow method, which is a technique that categorises requirements into Must have, Should have, Could have, and Will not have. Table 8 provides a summary of the identified requirements of the data physicalization system for library occupancy data, offering an overview of the prioritisation of the different features of the system. Although this overview offers an aid for designers and developers, considering that these requirements were based on a hypothetical design, it is recommended that this phase is revisited for adjustments if the system is to be implemented in a real-world setting.

Table 8. Functional and non-functional system requirements prioritised following the MoSCoW method.

MoSCoW	*Nr.*	*FR/NFR*	*Requirement*
Must have	1	FR	The system must show real-time library occupancy data of specific library areas.
	2	FR	The system must only collect the necessary data for the data physicalization.
Should have	3	NFR	The system should include accessible design features.
	4	NFR	The interaction with the system should be simple, so new users can immediately make use of it.
	5	NFR	The system should minimise energy consumption.
	6	NFR	The system should include materials that are cost friendly.
Could have	7	FR	The system could allow users to select a specific library area to be shown by the data physicalization.
Will not have	8	FR	The system will not show comprehensive occupancy information such as predictive occupancy data or occupancy patterns.

6.1.3 Final design description

Based on the requirements of the system and the original concept of the data physicalization, a final system design can be defined. The idea of this system is to present occupancy data within the library building, by using a large light emitting object (the fibre optic flower) at the entrance and with lights across the ceiling to convey this information. The main goals of the system are to give library visitors an immediate understanding of the overall occupancy level upon entering the building and to guide them to available spaces.

Sensor integration

A key consideration for the design is determining the areas that the system should highlight across the ceiling. This decision influences not only the design of the system, but also the integration of sensors around the library necessary to detect occupancy with a certain precision. Currently, the sensor setup within the library does not include sensors for every seat and space, although there are pilot projects running to investigate sensors for possible expansion and more detailed monitoring. Therefore, for the continuation of the refinement of the system, the sensor setup will be extended to monitor all unique study areas, which includes a variety of spaces such as silent and non-silent areas, desks with monitors, group study cubes, project rooms, and private study rooms.

Data presentation

Although each unique seat will be monitored by the system, a selection of the areas highlighted by the system is done to prevent cognitive overload and maintain a certain level of clarity of the data presentation. The system will show four different study areas: study seat, monitor seat, individual study room, project room. This decision is based on the outcomes of the focus group and the library wide survey that were conducted, where students highlighted these study areas to be of interest. In the data

physicalization, each area will be represented by a specific colour, limiting the palette to four easily distinguishable hues. The colour palette will be chosen based on its level of accessibility to all users, including those with colour vision deficiencies.

User interaction

Another consideration for the system is the level of interaction between the user and the data physicalization. In the original design idea, the user can only passively interact with the data physicalization through observation. However, the user engagement can be enhanced by moving towards more active forms of system interaction. One suggestion made was to integrate a certain navigation mode, to enable users to select a certain space to be presented by the data physicalization. For instance, when the user selects a certain project room, the lights can guide them to the right place. To integrate such a navigation mode an interface should be added to the system that allows users to select and be guided to a specific area with a light path across the ceiling. To avoid confusion, this navigation feature will include a timeout mechanism to reset the system to its normal state.

Interface design

The interface of the system, that enables users to select and be guided to a certain area, could entail many different shapes and forms. Although a physical interface may be possible, the use of a digital interface offers a level of flexibility and ease of updates, which is preferable as the interior structure of the library can change. Therefore, the system will have a digital display that provides users with a platform to select a certain area to be presented by the data physicalization. Moreover, there needs to be some indication shown that enables users to understand the meaning of the various colour hues shown by the physicalization. The system will provide the colour scheme with descriptions and accompanying icons for each study area, to enable users to correlate the colours presented by the system with their respective study areas. Additionally, this display could have a user feedback mechanism where library visitors could provide comments, suggestions, or questions about the system.

Conclusion

In summary, the system will display real-time occupancy data at the entrance of the library and across the ceiling in the building using coloured lights. A distinctive light object, the ‘fibre optic flower’ at the entrance, will offer an immediate overview of the overall occupancy by the number of illuminated lights, while light paths on the ceiling can guide visitors to available study spaces. The different light hues correspond to four study areas: study seats, seats with monitors, individual study rooms, and project rooms. Additionally, the system includes an interactive element that allows users to highlight a specific area with a fifth colour. This feature is accessible with digital interfaces located at the entrance and other points within the library. The system tries to empower library visitors with the occupancy data and enhance their experience by streamlining the process of finding available study areas directly within the building.

6.2 Functional architecture

To get a better understanding of the logic behind the system and the communication flow, a flowchart has been created. Additionally, each individual part has been described to give an in-depth overview of the various components of the system and how they work together.

6.2.1 System diagrams

Overall, there are four main components in this system interacting with one another. On one hand there is the data collection system involving a variety of sensors placed throughout the entire library building to sense the occupancy of specific areas, such as study places, project rooms, and monitors. On the other hand, the system involves the occupancy information output, involving the light plant at the entrance and the lights across the ceiling to communicate the data directly to library visitors. Lastly, the fourth component involves the input device for indoor navigation with the lights across the ceiling, involving the digital interface placed at the entrance of the building and in other strategic places in the library building. A simple overview of the inputs and outputs of the system is demonstrated in Figure 34.

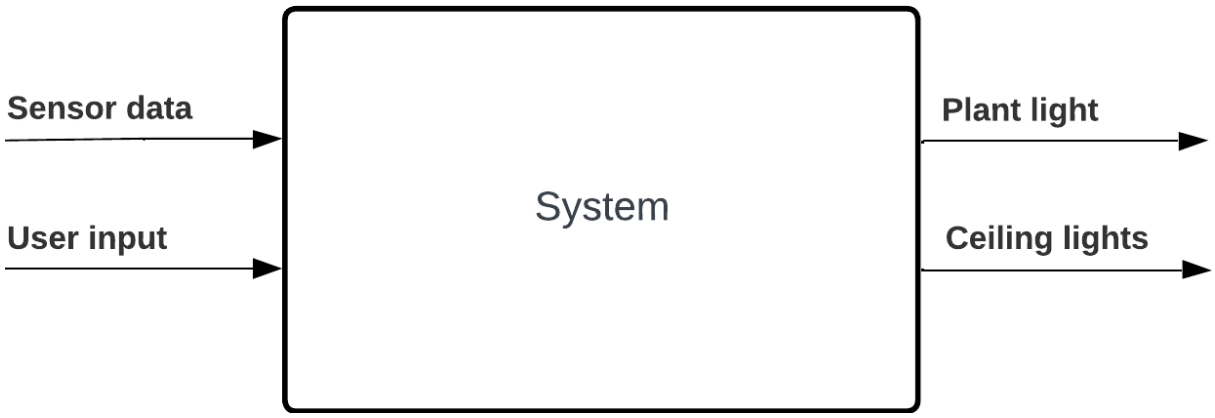

Figure 34. Diagram with the system inputs on the left side and system outputs shown on the right side.

As the library at the University of Twente has three floors, each one exhibiting a different combination of study facilities:

- *First floor*: study seats, individual study rooms, project rooms
- *Second floor*: study seats, monitor desks, project rooms
- *Thirds floor*: study seats, individual study rooms

The system integrates each of these floors, by placing sensors at each of the study facility elements and extending the coloured cables across all ceilings. The interaction between the different system components involves the sensing and sending of the real-time occupancy data by the installed sensors to a database which uses the input to run a piece of software controlling the data physicalization output. This program uses the input from both the database and the digital interface, that can be used by users for navigation within the library building with the lights across the ceiling, to output program prompts to the main light plant. This central light plant is connected to every cable running across the ceiling, forming the main base of the physicalization. An overview of these interactions is shown in Figure 35.

The decision-making process of the output of the physicalization software program involves the binary activation of the light cables leading from the light plant to the individual seats and a specific algorithm for the pathfinding light activation upon request from the user at the digital interface. This activation of lights involves a set timer to disable the light path after a set time. A flow of this light activation flow is demonstrated in Figure 36. In essence, each seat, monitor, or room in the library has one corresponding light cable, running from the ceiling above the area towards the light plant at the entrance of the building. Once occupancy is detected at the place, the corresponding light will turn off from above the place all the way towards the light plant.

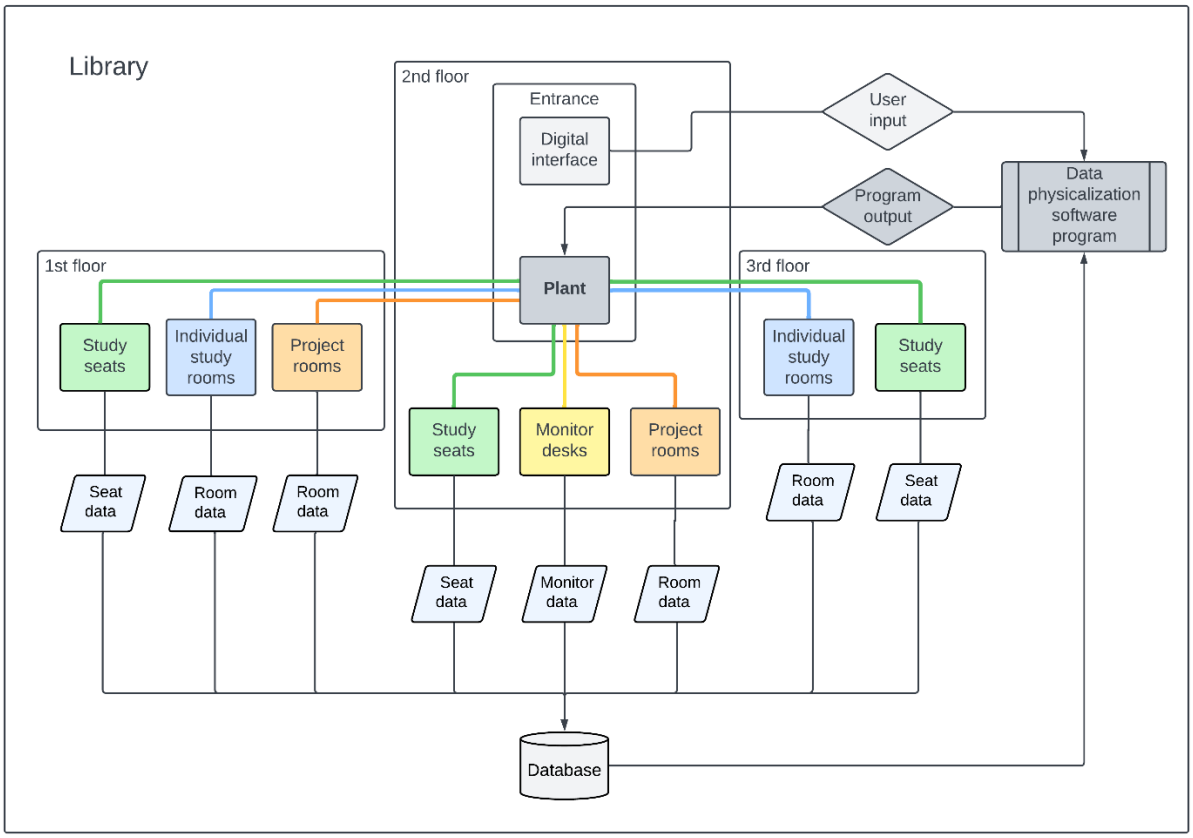

Figure 35. Diagram of the communication flow of the different elements of the occupancy data physicalization system inside the library.

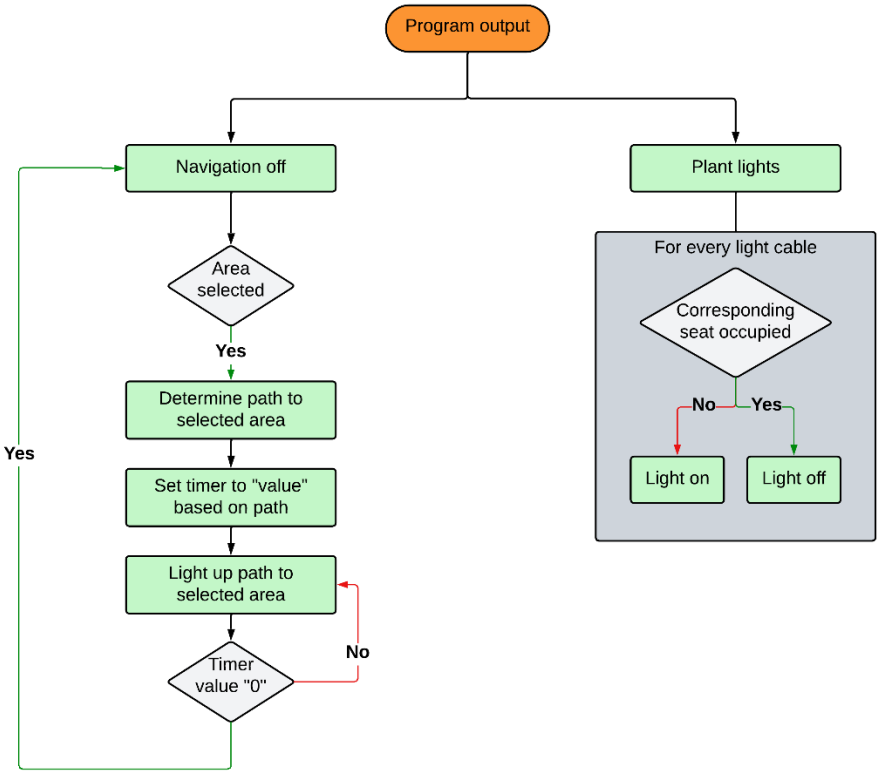

Figure 36. Light activation decision flowchart of the data physicalization.

6.2.2 Hardware

The hardware of the system involves two main parts: the input side, including all the sensors and other devices to obtain the real-time occupancy information from the library, and the input from the digital interface, and the output side that includes the plant of lights at the entrance of the building and the lights across the ceiling.

Sensors

Currently, the library at the University of Twente has integrated a sensor system with six distinct types to automatically regulate the indoor climate and inform their management and operations. These sensors are strategically placed throughout the library and include detectors of changes in environment, such as motion or temperature, in large spaces and project rooms to automate lighting and climate control to optimise the use of the library's energy resources. Additionally, people counters were initially installed during the COVID-19 pandemic to monitor the real-time occupancy. In the last months, the library has started a pilot project with DSI to investigate the effectiveness of certain sensors that can detect desk and monitor usage. The idea of this project is primarily to investigate the most accurate sensors to analyse if in a later stage it might be possible and useful to implement these sensors in more places throughout the library. With this information, the library can not only regulate the energy usage for these specific places, but also make informed decisions about its indoor interior layout. An overview of the used sensors is presented in Figure 37.

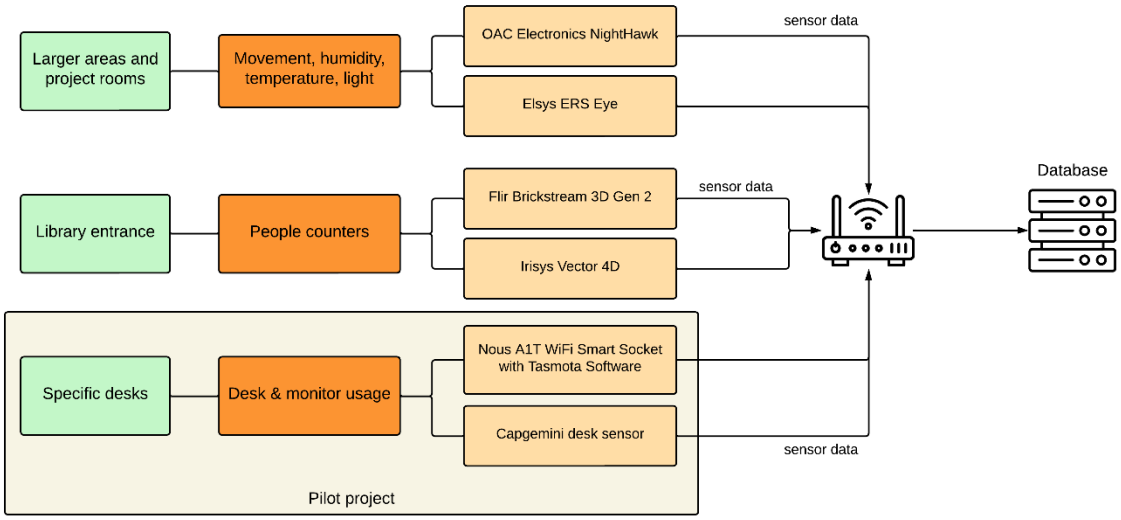

Figure 37. Overview of the sensors currently installed in the library at the University of Twente.

By extending the implementation of the desk and monitor sensors to each individual seat and monitor throughout the entire library building, the sensor input part for the data physicalization would be facilitated. This could be done with the sensors the library is currently investigating but could also involve alternative sensors that are small, non-intrusive, and have a low risk on privacy breaches, such as the wireless desk occupancy sensors from disruptive technologies [65].

Lights

In the original design of this physicalization idea fibre optic cables were suggested as the material for the light indication. Although fibre optic cables are great for transferring light from one place to another

and is a relatively cheap material, it is less optimal for directly presenting light across a larger area with a light background. Since the library is illuminated while open for visitors, this material might pose issues in its application for the data physicalization. Two alternatives might be suitable.

On one hand light emitting diode (LED) cables with addressable points would allow for large distance light distribution and flexible navigation opportunities. By integrating these types of lights, navigation could be done from any point in the library as the path could be individually activated as the small light units are individually addressable. The costs for building such a system and the voltage requirements may however be challenging for actual implementation.

Another alternative is the use of Electroluminescent (EL) wire, which is a flexible, thin copper wire with a specific coating that produces light when a current is applied to it. Although the individual parts are not addressable, EL wires seem fit well for being integrated into this data physicalization system as they are flexible, continuous lines of visible light that could be spanned from the main light plant all the way towards the individual seats.

However, EL wires would not actually allow for the navigation feature of the system to be functional, as the wires are not able to take on a different colour. Therefore, the consideration in choosing the light material for the system is dependent on the preferred functionalities. Depending on the presence of the navigation feature, the data physicalization needs either four or five distinct colours for indicating the various library study areas. In the continuation of this specification the system design without a navigation system is assumed.

Control unit

The control unit of the data physicalization system would be hosted in the pot of the light plant. In this hollow, covered area the necessary computational units that are wirelessly connected to the database would be placed. This could be a Raspberry PI that is connected to multiple Arduinos that are connected to the individual EL wires. In this way, the Raspberry PI would be the main control unit of the output system, while the actual activation of the wires would be done by the Arduinos. Furthermore, the plant pot should be connected to an energy source, which could be done via the ceiling as the EL wires would cover the energy cables.

6.3 Implementation

In this section a description of the implementation implications of the data physicalization system is provided, involving AI generated visualisations of the system and walkthrough of the possible user interactions.

6.3.1 AI generated system visualisation

To get a grasp of the data physicalization idea in a real-world setting, OpenAI's ChatGPT was used in private communication to generate visualisations of the data physicalization system by providing simple sketches and a description of the system. One of the results can be seen in Figure 38.

Figure 38. A visual of the data physicalization system in a library setting. Although not exactly the same as the idea, this visual shows the idea of the light plant at the entrance of the library building, showing the pot and the coloured lights moving towards the ceiling (OpenAI's ChatGPT, private communication, 13 February 2024).

6.3.2 User interactions

Scenario 1

Alex is a Biomedical Engineering student who has an exam coming up and prefers studying in a quiet, individual study room. As Alex arrives at the library building, he notices the light plant at the entrance. The plant shows quite many illuminated lights, which surprises Alex as he had assumed that it would be busier at this time of the data. He identifies the light hue associated with the individual study rooms and looks up towards the ceiling to find its light paths. Although he would have preferred the rooms at the third floor, the lights only indicate free individual study rooms on the first floor. He follows the illuminated path on the ceiling and finds a free study room.

Scenario 2

Mia is working at one of the monitors at the library as she has a programming project due at the end of the week. She receives a WhatsApp message from her friend Lauren asking her if she is studying at the library. Mia answers that she is indeed working in the library on an assignment upon which Lauren asks her if she could check if any project rooms are free. Mia remembers seeing the colour for the project rooms brightly at the entrance of the light plant at the entrance of the building. She looks across the room upon the ceiling and indeed sees that the coloured lights for the project rooms are lit. Mia texts Lauren that it seems that rooms are available. Fifteen minutes later Lauren arrives at the library and finds a free project room.

7 Insights and reflection

This chapter provides insights derived from the exploration and creation of the data physicalization design space, as outlined in Chapter 5, and the lessons learned from the participatory design workshop. The aim is to discuss the implications of these findings for the design and implementation of physicalization systems for enhanced communication of building data. Furthermore, this chapter presents an assessment and evaluation of the participatory design methodology that was used to generate physicalization designs in a user-centred, collaborative manner.

7.1 Design space insights

In this section, various design dimensions from the explored design space and several data physicalization ideas are discussed to provide insights and understanding of their implications and potential applications in different contexts.

7.1.1 Seamless integration of portable data physicalizations

As the participatory design workshops were created to design for distinct audiences, one targeting the private audience and the other a semi-public audience, this difference significantly influenced the resulting physicalization concepts. Interestingly, many of the designs created for the private audience involved wearable or portable devices. The students seemed to be focused on the possibility of these devices to be carried by the user to allow them to access the data from any place, which would be preferable in certain situations. Given their compact nature, these physicalizations typically were constrained in representing various data types, often requiring the users to memorise methods for specific data retrieval rather than intuitively perceiving the information through the physicalization itself.

Despite these limitations, several innovative physicalization concepts emerged that incorporated multiple data types. The Library map card (I6) particularly stood out, as it seamlessly integrates area-specific library occupancy data into an everyday item. This concept involves a simple card, designed with a layout of the library with embedded light indicators to reflect the occupancy levels across different areas. While this idea might resemble the functionality of digital maps on handheld devices, the Library map card distinguishes itself with its simple, straightforward interface and unobtrusive design. It enables users to intuitively understand occupancy data and enhances accessibility by allowing users to easily carry the device around. This specific design shows how physicalization concepts can redefine data communication by seamlessly blending digital information with common objects to provide users with a non-intrusive yet intuitive data access method.

7.1.2 Private and personal audience

In exploring the design space, a distinction emerged within the private audience category of the audience dimension derived from established design space frameworks. This category involves data physicalizations that are situated in private environments, such as home, or those carried by individuals. While these physicalizations primarily communicate data to the individual user, they may also be incidentally accessible to others, like visitors in a home. However, our analysis of design concepts for library occupancy data physicalizations revealed that in some cases when bystanders encounter physicalization objects, they might not be able to grasp the communicated data. For instance, designs like the Vibration keychain (I2) and the Responsive jacket (I8) require direct, tactile proximity from the user to convey the information. Therefore, bystanders might observe the data physicalization, but cannot experience the communicated data. This distinction is important to highlight as it shows potential for

creating data physicalizations that communicate sensitive information in a way that is intentionally shielded to observers, thereby safeguarding the privacy of the user and the information.

7.1.3 Subconscious interaction

The investigation of the design space also highlighted the interaction dimension, a common aspect in existing data physicalization frameworks. While most physicalizations from the participatory design workshops involved passive interaction, the Birdsong system idea (I24) particularly shed light on this dimension with its unique interaction approach. This physicalization idea communicates library data through playing specific bird songs in the outdoor area adjacent to the library corresponding to the various occupancy levels, blending the data with the natural environment. Users might not initially recognize the sounds as data communication but rather as ambient environmental noise, pointing at a level of interaction that could be considered even more indirect than passive. However, over time, it is possible that users may subconsciously correlate the bird songs with the indoor occupancy levels, learning to interpret this subtle data presentation method.

Although this communication method is still untested and its effectiveness therefore uncertain, this approach introduces a unique aspect to data physicalization worth exploring further in different contexts or for various data types. By blending data seamlessly into the environment, this method could achieve a form of data communication that is both unobtrusive and, through long-term exposure, enhances the accessibility of the data without apparent user awareness. This immersive approach to communicating building data fosters a natural discovery of information, not requiring the need for active user engagement. Such a method could potentially be valuable in contexts where the data is not required by all, facilitating a passive yet insightful interaction with the environment and the data.

7.1.4 Temporal design scope

The generated physicalization concepts for library occupancy data reveal a wide range of possibilities. As uncovered by the analysis of the ideas and the definition of the design space described in the previous chapter, the temporal design scope is a dimension that emerged from the data but was not yet defined in other established data physicalization design spaces (to our knowledge). However, this has a logical explanation, as the creation of this design space was based on data physicalization concepts and design ideas, rather than already created works which are typically used to define design spaces. Therefore, a dimension focused on the expected time frame in which a data physicalization may be created is not relevant. Still, defining a design space based on data physicalization concepts may allow designers to ideate about future applications, and this could be beneficial. As technology advances and environments constantly change, this method could be seen as an opportunity to explore innovative ideas for physical data interfaces that may be realised in a future time. It broadens the scope of design possibilities and could be valuable in exploring a variety of opportunities of communicating building data that may be considered in the creation of future projects.

For instance, if there would be a case where a new building is being designed for a university campus, it is possible that the actual construction of the building might happen in a few years. This means that certain implementations of data physicalizations requiring a complex infrastructure or technologies that are not yet available, might be feasible in a few years, enabling the decision-makers to consider these ideas for actual implementation. Although high tech, complex solutions may not always be necessarily preferable, introducing methods to explore future opportunities could still bring valuable and insightful ideas to the development process.

In essence, by designing data physicalizations for immediate, near, and far futures, specifically for presenting building data, designers and architects can be introduced to physical data communication methods that could be integrated in future buildings to enhance communication and accessibility of building data to empower building occupants. It allows building development to become more data-focused in its design approach by establishing the integration of sensors and actuators into the built environment in an early design phase to improve and enhance the communication, use, and accessibility of building data.

7.2 Participatory design workshops

This section includes a reflection on the participatory design workshop performed during this study to generate various data physicalization designs for library occupancy. This reflection is meant to provide insights and understanding of how the deliberate study design choices for these workshops influenced the outcome.

7.2.1 Inclusion of focus group

A focus group was used as an ice breaker during the design workshop after the initial introduction of the workshop session. Initially, an ice breaker was designed that did not involve a focus group, but rather an activity to get the participants engaged. However, due to the incorporation of a focus group for another part of this study, the option to use this as the ice breaker arose. After discussing this opportunity with the research supervisors, an adjusted workshop plan was created with the integration of the focus group. One of the challenges arising from this decision was finding an effective way to merge the two methods without overwhelming the participants. Therefore, the individual parts of the workshop sessions were made relatively short, to not exceed a limit of an hour and a half for the entire workshop, allocating 20-25 minutes for the focus group. The integration of the focus group appeared to have positively influenced the group dynamics during the main design sessions. As the participants were already encouraged to speak up and share their ideas, opinions, and feedback about occupancy data, it seemed to have helped the participants to feel more comfortable sharing ideas. Since the expression of ideas is essential in rapid ideation, this inclusion of a focus group as an ice breaker appeared to be an effective method.

7.2.2 Brainstorming materials

Initially the design materials involved the physical prototyping tools and the data types as explained in Section 5.2.2. However, after running the pilot workshop, it showed that the setup did not seem to be effective in encouraging or assisting the groups to generate multiple physicalization ideas, although this was the principle aim of the design phase. The participants focused on discussing certain ideas, but then sticking with one concept. Therefore, alternative approaches and the addition of certain materials and aids were discussed to change this for the subsequent design workshops. Ultimately, a specific slide was added to the presentation projected on the large display in the workshop room with an instruction for the rapid ideation process for the individual designs, as shown in Figure 19. During the introduction session, this instruction was discussed with the participants and during the design session, it was displayed on a big monitor. Additionally, on the design tables three stacks of memos were placed with several pens. For each of the colours, a different question regarding the context and components of the data physicalization ideas. This was added to enable participants to explain concepts to each other in a structured manner, addressing three main components: data type, data translation, and intended use. These additions to the workshops seem to have been effective in fostering a design process where the participants created multiple design ideas. As a result, the tables after each session were filled with the

various coloured memos that were actively used by the participants in addition to the physical prototyping tools.

7.2.3 Composition of design groups

In the early stages of defining the design workshop study, the main design phase involved an individual brainstorm and concept development as opposed to a collaborative design session. This was initially chosen to gather unique insights and concepts from each individual participating the workshop session. However, a possible challenge was predicted in engaging students from non-design disciplines in a creative development process involving a concept they might not yet be familiar with (data physicalization). Therefore, the suggestion arose of involving students that both exhibit extensive brainstorming and iterative design experience as well as familiarity with the concept of data physicalization, which is the case for student at the University of Twente majoring in Creative Technology. Ultimately the recruitment process involved the inclusion of sufficient Creative Technology students to form groups with at least one of them, while involving enough students from other majors to keep a good distribution of participants that well reflect the University's student body. Although no official evaluation was done on the effect of involving Creative Technology students in each of the groups, the creative development in each of the groups during every session seem to have been very effective. Especially given the short time frame of the design sessions, involving experts in the field of rapid design and brainstorm that also are familiar with the data physicalization concept seem to have been a good choice for the effective outcomes of the workshop sessions.

8 Discussion

This chapter presents a discussion of the conducted research, including an assessment of the choice of research methods chosen to answer the research questions, the execution of these methods, and the overall limitations of the research. The discussion will not only evaluate the overall research project, but also informs improvements that could inform future research.

8.1 Choice of research methods

To answer the main and sub research questions, it seems that the chosen methods, including the survey, focus groups, participatory design workshop, and thematic analysis were mostly effective for obtaining essential information and analysing the results. However, concerning the sixth sub research question "How would they want the information about library occupancy to be physically communicated?" there seems to have been a lack of methods to evaluate the physical communication methods among students. Although the research involved a user-centred, collaborative approach in exploring the design opportunities, there was a significant lack of evaluating the created designs with users. Still, the chosen research methods seem to have been fitting for answering the other five sub research questions, combining both qualitative and quantitative methods.

Although this was not a specific research question, the further specification of one data physicalization design was found as an additional method to inform the main research question and evolved from the objective of the research project to demonstrate a possible application of a data physicalization in a real-world context. The method used to further specify the system seems to be somewhat appropriate, although it typically involves the rapid iteration of prototypes which was not one of the objectives in specifying this data physicalization as it was not part of the research scope.

8.2 Execution of research methods

In this section the execution of the individual research methods is assessed and discussed to reveal any potential limitations, unforeseen challenges, and areas for improvement.

8.2.1 Survey

After releasing the survey, it became apparent that the demographic question regarding the major of the student was not clearly formulated, resulting in some unused data points. Although the questions were discussed beforehand, this problem could have been avoided by running a small pilot test. Additionally, although the survey had a relatively high number of respondents, the time period only involved a month of the academic year in the first semester, which could mean that possibly only a specific sample of the student population was reached. To capture a representative sample, the survey should be conducted over a longer period of time and allow for students to answer the survey multiple times to observe how library usage may change over time.

8.2.2 Focus group

The focus group was deliberately kept short, around 20 minutes, as it was part of the participatory design workshops. As a result, more in-depth conversations may not have been able to completely emerge, causing the overall research project to miss out on valuable data points. One important factor that may have influenced the results is the population distribution of the focus group that included a large number of Creative Technology students. Although this was due to the need of these students to form a substantial part of the population for the participatory design workshops, it could have influenced the

focus group dynamics (as some participants already knew each other, while others did not) and the results. Still, the focus group session themselves went well, allowing all participants to share their thoughts, opinions, and ideas.

Thematic analysis, the thematic analysis used to evaluate the results from the focus groups was done with a single researcher, which may have resulted in a bias in the data and emerging themes. Furthermore, the thematic analysis of the focus group was done around three weeks after the sessions were conducted due to the priority that was given to analyse the results of the participatory design workshop first. Although it does not seem to have influenced the analysis process, it may have been better to perform this analysis directly after the focus groups were conducted, as this could have ensured an enhanced recollection of the discussion and a more immediate interpretation of the responses given.

8.2.3 Likert scale questionnaire

The questionnaire with a Likert scale that was conducted as part of the focus group faced some challenges. The participants mentioned that two of the data types seemed to be the same but were differently formulated. Although this was intentional, it did cause some confusion among the participants. The space provided to either draw or explain certain data that the participants seemed to find useful resulted in a beneficial addition to the overall questionnaire, allowing the participants to explain their choices better and in this way provide some additional qualitative data to this quantitative research method.

8.2.4 Participatory design workshop

The participatory design workshops were conducted by the main researcher, which did not form any issues for the session, however it would have been beneficial to involve at least a second researcher to enhance the overall procedure of the sessions. The pilot session of the workshop was essential in identifying the missing elements for a fruitful design session among the participants. The students did not seem to create multiple data physicalizations, but rather focus on just one single idea. Therefore, after the pilot session, a slide was added to the presentation with a structured method for the design session and brainstorming aids were added to the provided materials to assist participants in their collaborative design process.

Overall, the execution of the remaining workshop session seems to have been successful, although the presentation and feedback session could have been longer to better evaluate the various physicalization designs. The deliberate choice to involve at least one Creative Technology student per design group seems to have positively influenced the overall process of the design phase. Moreover, including a focus group session as the icebreaker element before the design session appears to have facilitated a more open and collaborative environment, encouraging the participants to share ideas and feedback more freely with each other. Although the workshop sessions themselves were well-structured and effective in obtaining the necessary information, additional workshop sessions or evaluation sessions may have enhanced the overall exploration of design ideas.

8.2.5 Categorisation method

The mixed method approach in categorising the various data physicalization ideas seems to have been effective in defining a design space. Although the initial thematic analysis was performed by a single researcher, through integrating and comparing themes from various design spaces extracted from existing literature, the categorisation seems to have been thorough. Still, the execution could have

included more data physicalization frameworks and established dimensions to enhance the comprehensiveness and depth of the final design space.

8.2.6 Specification of one data physicalization

The specification and setup of the realization of one data physicalization design, found its challenges due to the lack of user feedback and time constraints. Following the scope of the research project, the refinement of the system did not involve the iterative process of creating physical prototypes to get user feedback to further detail the requirements of the system. Instead, the results and insights from the first part of the conducted research, involving the survey and focus group session, were used as the main base for the refinement of the system. Although this was a good alternative in the context of this project, it still resulted in the lack of actual user feedback which could have made the final design more user centred.

8.3 Overall project limitations

The project timeline brought constraints to implement comprehensive evaluation of the data physicalization designs generated in the participatory design workshops. This limited the ability of the research to assess user preferences and the effectiveness of specific concepts with a broad library user base. Additionally, the research did not extensively seek direct feedback from the library on the findings throughout the research process. Although the library staff contributed to the initial research setup, ongoing involvement throughout the research process could have enriched the outcomes, by offering essential insights into how the designs could be practically implemented and integrated with existing library systems and how they would expect their users to interact with the physicalizations.

9 Conclusion & future work

This concluding chapter will present the conclusion regarding the conducted research, by providing the findings related to the main and sub research questions as formulated in Section 1.3, and outlines directions for future research and potential continuations and improvements of the current research.

9.1 Research findings

This section presents the findings and responses for the main and sub research questions. The outline will first focus on the findings related to the sub research questions, which will guide answering the overall main research question of this project. The presented insights are derived from the data collected from the survey, the focus groups, and the participatory design workshops.

RQ1.1: What occupancy information do the students need?

The findings from the survey and focus groups indicate that students show an interest in various types of occupancy. Real-time occupancy data indicating the availability of free spaces emerged as the most preferable data type among students. However, if enriched with metadata about the specific type of available study places or project, this data would be even more useful. Additionally, the findings indicate that students are interested in more sophisticated occupancy data, such as occupancy patterns and occupancy forecasts.

RQ1.2: When do they need the occupancy information?

The research reveals that while some students plan their library visits in advance, others decide to go spontaneously. Changes in study habits over time influence this planning behaviour, which are dependent on the workload and changes in academic phases, such as exam weeks. Therefore, students may have the habit of planning their library visits ahead some weeks of the module or academic year, while in other moments they might spontaneously decide to visit the library. Additionally, students mention an increased interest in receiving occupancy information during busier periods, such as exam weeks, when they know that the occupancy within the library may be higher.

RQ1.3: Where do they need the occupancy information?

The majority of the students plan their library visits either at home or while on campus, with occasional decisions being made by students who are in transit. Moreover, once inside the library, students may also benefit from occupancy information depending on its type and the needs of the user.

RQ1.4: Why do they need the occupancy information?

The research identified that the need for occupancy information is driven by their study habits and behaviours, which often fluctuate during the module and over the academic year. Students would use this data to make informed decisions about when to use the library, aiming to choose the most optimal study environment. This is especially useful during exam weeks, when the highest occupancy rates occur, and students would benefit from having less stress for finding available study spaces. Real-time, non-specific data could allow students to grasp the overall crowdedness in the library, potentially saving them from an unnecessary trip if the environment is unsuitable for their needs. More detailed, area-specific data could provide valuable insights into the availability of specific resources, such as monitors or project rooms, influencing the decision of students to visit. This detailed information could also help in efficiently locating available study spaces upon arrival. Sophisticated occupancy data, such as occupancy trends and forecasts, are particularly useful for planning visits in advance, enabling

students to select times when the library's indoor environment is most suitable for their study preferences.

RQ1.5: Who needs what occupancy information?

As the student body at the university is very diverse, so are the library users and their occupancy information needs. These needs can be categorised based on the location of the user relative to the library: those already inside the building and those outside. Additionally, these needs vary based on the temporal frame with regards to the library visit: students planning their visit in advance or deciding to go spontaneously.

For students already inside the library, real-time, area-specific occupancy information would be most useful. This data helps them locate available resources and study spaces efficiently, minimising the time spent searching for an available place. On the other hand, students outside the library require a broader spectrum of occupancy information. Those planning their visit in advance would benefit from sophisticated occupancy data, such as historical occupancy patterns and predictive occupancy forecasts. For students deciding to visit the library spontaneously, real-time overall or area-specific occupancy levels would be most useful. This information provides a quick overview of the current library level of crowdedness, helping the students decide whether the library environment fits their study needs at that moment.

RQ1.6: How would they want the information about library occupancy to be physically communicated?

The participatory design workshops revealed a large variety of possibilities to physically communicate the library occupancy data, demonstrating how data physicalizations can be designed to address different needs and preferences of users. Although some designs seemed to be more of interest or preference to the students than others, the research did not involve sufficient evaluations of physicalization concepts with a larger body of users to find specific insights on their preferences. However, as discussed in Chapter 8, this point could be addressed in future research.

RQ1: How can a system be designed to communicate real-time library occupancy information to students?

Following from the finding for the sub research questions, the design of a system to communicate library occupancy data to students should include a versatile platform or combination of communication methods offering real-time and sophisticated occupancy information, specifying the study areas and facilities. The information should be accessible both inside and outside the library to support the specific needs of various users. The system could incorporate physicalization methods both within and outside the library space, enhancing accessibility, engagement, and intuitive interaction of the communication method by merging digital data with the physical environment. A specific data physicalization concept, specified in Chapter 6, offers a detailed example of how such integration could be realised. Lastly, the system should be designed to complement the library services and integrate well with existing systems in their building.

9.2 Implications

This research project has three main contributions: the insights into the requirements of a system that communicates library occupancy data to university students, the dimensions of a design space for data physicalizations of library occupancy, and the specification and outline for the realisation of a specific data physicalization concept that communicates occupancy data directly in the library environment.

These contributions not only inform the library at the University of Twente in its development of an occupancy data communication system with a user-centred approach, but it can also inspire other researchers, designers, and even architects with its findings. Specifically, the defined design space and the specified data physicalization system present opportunities to create more immersive and integrated data communication methods that not only transforms data into intuitive experiences, but also show how data physicalizations could create new relations between users and their environments. Ultimately, this research project could serve to pave the way towards a more data-driven architecture that focuses on empowering occupants by making building data more accessible.

9.3 Future research

To address the limitation of this research project identified in Chapter 8, future research could focus on integrating and enhancing the evaluation phase by incorporating a wider range of user testing methodologies and stakeholder feedback. This would involve not only assessing user preferences but also test the effectiveness and usability of various data physicalization concepts in real-world setting. Integrating an iterative design process would further allow for the continuous refinement of these systems based on direct user input and feedback.

To improve the validity of the research findings, future studies could consider a longer data collection timeframe and conduct thorough pilot testing for surveys and questionnaires. This approach would ensure a broader, more representative inclusion of user perspectives and increase the reliability of the collected data.

Building on the foundation laid out by this research project, future research could aim to develop and implement a functional system for communicating library occupancy data at the University of Twente. Utilising the insights and system requirements outlined in this study, the development of an actual system could serve as a practical test for the proposed requirements, allowing for evaluation, validation, and adjustment of the system.

Additionally, the defined design space for data physicalizations of library occupancy data offers a valuable resource for further exploration. Future works could replicate the participatory design study and categorization methods used in this work to refine or expand the design space in similar or new contexts. This expanded design space could then serve a rich source of inspiration for designers, researchers, and architects involved in building data communication systems or smart building development.

Furthermore, investigating communications systems for other types of building data other than occupancy information could reveal unique opportunities. Exploring these areas could contribute to significantly to the broader field of smart building development and data communication, enhancing the accessibility of data, the integration of data in everyday environments, and demonstrate opportunities for making data communication more interactive and engaging for users.

Other directions that could evolve from this research could be focused on the actual development and implementation of a system that communicates library occupancy data at the University of Twente. The insights and system requirements presented in this work could inform this development and provide opportunities for physically communicating the occupancy data.

In conclusion, future research inspired by this work has the potential to significantly advance the field of data physicalization for smart building design, offering new insights and opportunities for creating user-centred, data-driven buildings.

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Appendices

Appendix A. Survey promotional materials

These QR code was printed out on papers that were placed strategically around the library building and the other visuals were used on the large displays in the library and on social media.

Appendix B. Survey conducted in the library

The online survey, with 9 questions, that was used to gather information for library users at the University of Twente, including the information letter and consent form.

Physicalization of real-time library occupancy data

Purpose of this research project

The purpose of this research project is to create and evaluate a real-time data physicalization that displays occupancy data of the University of Twente Library. The objective of the research is to design, create, and evaluate a data physicalization that not only provides valuable information but also seamlessly integrates in the campus environment and student life.

Goal of the survey

The survey is used in this phase of the study to gather essential information from students, which will be invaluable for creating an effective data physicalization. Your input will be used to determine the requirements, opportunities, and possible dimensions of the physicalization.

Survey participation

The survey will take approximately 3 minutes to complete. During the survey you should be safe from any sort of risk. The survey setup of this study has been reviewed and approved by the Ethics Committee Information and Computer Science.

You are allowed to withdraw from the study at any time. There is no penalty for not participating or for withdrawing from the study. If you want to withdraw from the study, you can notify one of the researchers. Any information gathered in the survey will then be deleted.

Your data

Some personal data will be collected for research purposes. You will have the option to not share this information during the evaluation. Your responses will be anonymized and aggregated for analysis purposes. As the data will be anonymized after collection, there is no option for you to request access to and rectify or erase this data after the survey has concluded.

All your responses and information will be kept confidential within reasonable limits. We will minimize any risks by storing all the collected data on secure servers that are only accessible by authorized personnel involved in the research. We will retain the data for a period of six to twelve months, after which it will be securely deleted. The privacy and confidentiality of your personal information are of utmost importance to us. We assure you that all data collected in this survey will be treated with strict confidentiality and stored securely.

You will have the decision to share your email address at the end of this survey. This personally identifiable information will be stored in Google Drive and will be used to contact you for further partcipation in the research project. The email address will only be used by the researchers that are involved in this study will be removed from Google Drive on the 1st of December 2023. This information will not be disclosed in any reports or publications resulting from this research.

Contact information

For any further questions please ask them to one of the researchers or send an email to s.m.fuentesbongenaar@student.utwente.nl. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researchers, please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl.

* Indicates required question

1. **Consent statements** *

I have read and understood the information given to me in this survey. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves the completion of a survey questionnaire by me. I understand that there are no risks involved in participating in this study. I understand that information I provide will be used for a bachelor research paper.

I understand that personal information collected about me that can identify me, such as [e.g. my email address], will not be shared beyond the study team. Future use and reuse of the information by others I give permission for the anonymised questionnaire answers that I provide to be archived, so it can be used for future research and learning.

Thank you for taking the time to participate in this survey. By choosing 'Yes' I confirm to understand and give consent for the statements as presented above. By clicking 'Next' below, I affirm the voluntarily consent to participate in this survey.

Mark only one oval.

- ◯ Yes
- ◯ No *Skip to section 3 (Thank you for your participation!)*

Survey questions

2. When did you decide to study at the library today? *

Mark only one oval.

- ◯ Spontaneously, right before going there
- ◯ Spontaneously, before going to the campus
- ◯ Spontaneously, during class
- ◯ I planned it ahead, less than 2 days prior
- ◯ I planned it ahead, more than 2 days prior
- ◯ Someone else planned it (e.g. for a group session or working together)
- ◯ Other: _____

3. Where were you when you made this decision? *

Mark only one oval.

- ◯ At home
- ◯ On campus
- ◯ I don't remember
- ◯ Other: _____

4. If you indicated in the previous question that you made this decision on campus, could you share where you were on campus? Were you in a lecture?

_____

_____

_____

_____

_____

5. What is your primary purpose for being in the library? *

Mark only one oval.

- ◯ Studying by myself
- ◯ Studying with others
- ◯ Meetings
- ◯ Using the library resources
- ◯ Other: _____

6. What specific information about library occupancy would be valuable to you? *

Check all that apply.

☐ Today's visitors history

☐ Same hour occupancy over the past 5 days

☐ Number of free seats

☐ Number of seats in use

☐ Other: _____

7. How does library occupancy information impact your decision to visit or avoid the library? *

Mark only one oval.

- ◯ To plan my library visits efficiently
- ◯ To choose suitable times for group study
- ◯ To select optimal study periods, especially for exams
- ◯ To find vacant seats or study rooms easily
- ◯ To check if the current library's atmosphere matches my study atmosphere preferences
- ◯ To avoid overcrowded conditions
- ◯ It wouldn't impact my decisions
- ◯ Other: _____

8. What is your major or field of study? *

_____

9. For this thesis project a design workshop will be organized that should not take up more than 1.5 hours. If you are interested in getting more information, please share your email address below:

_____

Thank you for your participation!

We want to thank you for filling out our survey and providing us valuable information.

If you still have questions or remarks, do not hesitate to reach out to us via email: s.m.fuentesbongenaar@student.utwente.nl.

Again, thank you for your participation and we wish you a nice day!

Appendix C Slides used during participatory design workshops

These slides were used during the workshops, read them from up left, downwards, up right, downwards.

03 - DESIGN SESSION

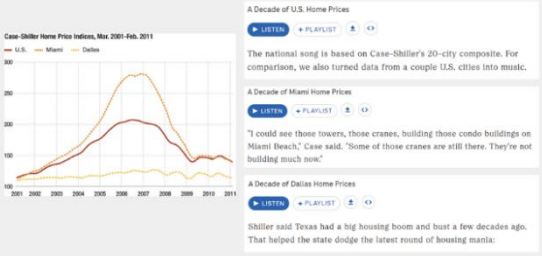
DATA PHYSICALIZATIONS

Data physicalizations embody information using physical materials and phenomena, such as water, light, paper, plastic, and even sound or vibrations.

To engage not just sight but touch, hearing, smell, and taste.

Transform data into physical forms for a more **natural and intuitive interaction** and understanding.

03 - DESIGN SESSION

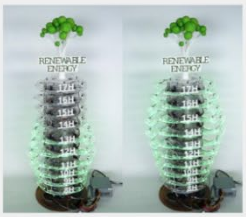


03 - DESIGN SESSION

SOME EXAMPLES

03 - DESIGN SESSION

CairnFORM: a Physical Ring Chart



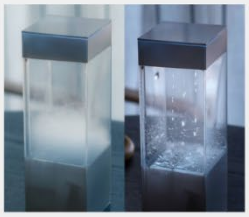
CairnFORM is a 3D object that represents a ring chart, with expandable rings and LEDs. It shows renewable energy data in a format that's readable from all directions, visually demonstrating how energy use changes over time.

Data Representation: Presents **renewable energy data** with **size of the cylindrical rings** and **lights**.

Advantages: The physicalization is suitable for **day-to-day environments** where it can enhance **awareness** and **engagement** in social settings.

03 - DESIGN SESSION

The Tempescope by Ken Kawamoto



It connects to the internet and recreates weather like rain, fog, and even lightning, right inside the box, making weather data something you can see and feel.

Data Representation: Physicalizes various weather conditions based on **weather forecast data** with **water**, **heath**, and **light**.

Advantages: Provides an **immersive experience**, enhancing understanding and engagement.

03 - DESIGN SESSION

LOOP: Physicalization of Personal Activity

It is an object with rings that change shape based on your daily activities. Each ring represents a day of the week, and the changing shapes give a visual and tactile representation of your personal activity levels.

Data Representation: Physicalizes the **number of steps** with the **position of the rings**. The outer ring shows the goal, the other rings represent the activity data per day of the week.

Advantages: Offers an **abstract yet intuitive** presentation of activity data, promoting **reflection and motivation**.

03 - DESIGN SESSION

Laina: Slow Exercising Feedback

A sculpture that moves and transforms to show how much and how fast you've run, giving you a visual and physical representation of your exercise data.

Data Representation: The **running route** and the **level of effort** (pace, heartrate) affect **which of the the pins come out at what lenght**.

Advantages: This data physicalization facilitates **deep reflection**, **anticipation**, and **exploration** of personal exercise behavior.

03 - DESIGN SESSION

DESIGN DIMENSION

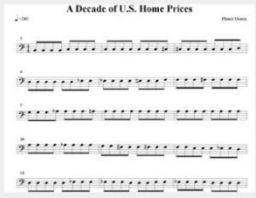
In this session you will be exploring designs for the **private environment**. This includes the home environment and portables, such as backpacks, water bottles, watches, laptops, phones, etc.

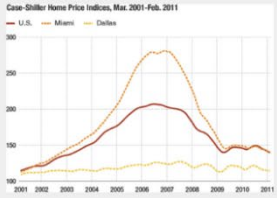
In groups, create designs of physicalizations that present library occupancy data in the private environment.

Think about:
- **which data** will be presented
- **where** it will be presented (on a desk, the wall, keychain, etc.)
- **how** will it be translated (light, sound, vibrations, etc.)

03 - DESIGN SESSION

U.S. Home Prices, Sung As Opera





03 - DESIGN SESSION

START DESIGNING!

1. Find your group
2. Design data physicalizations for occupancy data:
   - **select occupancy data** to physicalize
   - **brainstorm** about ways to translate the data into a tangible form
   - **create** a small prototype with the materials available or create a sketch
   - add a **memo** with:
     - **what** data is presented
     - **how** is the data presented (light, sound, vibrations, etc.)
     - **where** will this physicalization be placed? (on a desk, the wall, keychain, etc.)

You will have around **25 minutes** to design, create as **many physicalizations** as you would like!

Appendix D Likert scale questionnaire

Rate the occupancy data as shown above by filling in the accompanying numbers.

		NOT USEFUL		NEUTRAL		VERY USEFUL
1	**TODAY'S VISITORS HISTORY**	○	○	○	○	○
2	**SAME HOUR OCCUPANCY OVER THE PAST 5 DAYS**	○	○	○	○	○
3	**NUMBER OF FREE SEATS**	○	○	○	○	○
4	**NUMBER OF SEATS IN USE**	○	○	○	○	○
5	**PREDICTED NUMBER OF SEATS AVAILBLE AT 10 TOMORROW**	○	○	○	○	○

Is there any other type of library occupancy data you would see as useful?
You can draw/explain it here below or on the other side of this page:

Appendix E Tagged focus group transcriptions

Session 1

R: Yeah. OK. Then we'll go into the focus group. So what I'm going to do is I'm just going to ask some questions. Just answer freely and afterwards we're also going to fill in some small form. So first of all, how often, …, this is the wrong slide! I'm sorry this is not the correct slide. I did not change that correctly. OK, this is the right one. It's still the same question, just smaller. How often do you study at the library? Do you study at the library at all?

P1: I don't never.

R: Never?

P1: Never, in this building, no.

P2: Maybe like twice a year.

R: Specifically, twice a year away, why?

P2: Just they're only a few moments I can remember.

R: OK.

P2: Yeah.

P3: I used to. Like in my bachelor I did, but now not anymore.

P4: Hmm, I actually used to like to study quite a lot in library. As in, mostly when I have test week or exam week or something like that. So like the week before I I'll can be found here quite a lot. Uhh, and yeah, I, I just like. I think it's nice to have one certain space where you just go. Everyone there is pretty much working and silent and it's quiet and I think it is a nice space for that.

R: OK.

P4: So yeah. Nice.

P1: I find it a little bit like the first time I came here in the first year, like in the first week I was like, oh, it's gray, it's a box, no, not doing this.

P5: The spaces where you're next to the windows are quite nice, but the, some of the rooms are really depressing. Eh maybe once or twice per module, depending on whether there's like an exam you actually have study for or not. Eh, yeah, or like group work quite often in the library.

R: So that's for group work in the project rooms basically?

P5: Yeah, yep.

P4: Yeah.

P6: I just go there to study sometimes when I can't find the space anywhere else on campus, I'm like "Oh, perhaps at the library" and then.

R: I see. So where else do you study more often?

P6: Usually more on the other building sites. Anywhere where I can find a space usually. It's like "Oh, I can sit here. I can work here."

R: OK, for the rest as well? Or just like anywhere else on campus or do you study at home mostly?

P1: I like studying at Cubicus, because that's where our studies association is and that's where our, like the people that I know are. But also the new building the the I I

R: ITC

P3: Langezijds

P1: Yeah that one is really nice!

P4: Yes that one is amazing!

P1: And sometimes also Ravelijn.

P5: Depends on where my classes are. I'll, in like close by usually. Especially when it rains. Ehm, or near EduCafe which is near where my study association is, so.

P4: I normally just study like at home or at the library and I do every now and then think like, ooh, I should check out the new building because I heard so many stories about it and I went there once. So it was like "ohh yeah, I should go here to study more" and I've never done it. But mostly, yeah, or the library when I really know I gotta, like, focus for, like, really focus then I would prefer to go to library. So yeah, there's two options pretty much.

P3: Last year I stayed a lot at Langezijds when opened, but also a lot at Horst because we had many lectures there and at home now.

P2: At home, at a friend's place, or at Cubicus.

R: Ok, nice. Yeah, I mean, eh this is more related to the library, but I think most of you already mentioned this. So, this is good. So not necessarily related to the library, but how do you make the decision to study somewhere? So, I hear a lot is it's either rain, it's close by classes like you just choose where you already at. Is there anything else that makes this this like how you decide this or?

P1: Yes. Well, for me, I like, I, eh really depending on mood ehm and also of course like the obligations whether you have to be physically present at university or not. I live in the city center, so I like studying in the Public Library there. Or well mostly just in the cafe that belongs to the Public Library because I like fuzz, but not focused fuzz and I like that the fact that I don't know people there. Umm, while still being out of outside of your home. And, well it depends on the mood in which mood I am in. That's really, really dependent and whatever, how my concentration level for the day is, whether I wanna sit with people that I know, whether I don't wanna sit with people that I know.

R: It's very flexible, basically, yeah. OK. Is there anyone that has like a really rigid study routine, or also not really? Or had maybe in the past for a different eh?

P2: I think I do, compared to most students. But, yeah, it's just like mostly like in between 9:00 or 10:00 and 5:00 or 5:30. Like, that's the time when I spent on working, but yeah, it depends per day where I go, but that is like it's quite like established. Like in between these times basically.

R: OK, yeah, throughout the day you just decide basically where you go.

P2: Yeah, yeah.

P5: When I'm already on, like studying on campus, doing stuff I don't generally choose to go to the library that's more of a if it's planned in advance to go maybe with multiple people and like go early because there's not a lot of space and that's like a it's a different mindset to go to the library, for me personally to go to library, and like that's a different mindset to have. So that's usually planned in advance, for me.

P4: So for me it's like if would study at home, I know I'm probably gonna get distracted a lot and stuff and I just, the library is just this one, this is a place for me, also in my mind where I'm like, if I go there, I know I'm going to be able to focus, especially if I get one of those one persons room. Like, I'm not gonna get any distractions, I can just completely work for hours, just completely focused, and I like having that idea. So that's pretty much why I go there. And then also last year, like during pretty much every project we would go to the library for pretty much 80% of all the meetings that we had. We would just book a room there and then we would go there.

R: OK. Umm, yeah, so this is also more related. So I hear that a lot of people kind of decide already during the day, depending on where they are, ehm, that you decide to study somewhere. Is it normally that you also, if you're at home, you decide where you go for the day? If you have like a free day off, or do you just go to uni and then decide here what you're gonna work on or where you gonna work?

P2: At home, I think.

P5: If I have a complete free day, I'll think about it in advance, because otherwise why go? Because I can also study at home. Ehm, but if I'm if I have to go for something else, I'll be close by usually.

P4: Also, kind of depends on if other people are also already at the library whereas if I'm at home and some people are like, yeah, we're we're we're in the room at the library studying I will also join them, because studying together with other people is also nice.

R: So, ehm, I think what I basically wanted to know is like what is your decision making process, but I think you mostly answered that. Now looking more into for example, the data I can present. Ehm, umm, so just regardless of whether you study here or not, just imagine any building basically. There is maybe some data available at some point and what I would like to know is would you if you had access to this data and you go like before you go to this place which you access it and there are some examples of like types of data that could be presented, would they even make uh would they even influence your decision making first of all and also which one would you maybe value more or less compared to the other ones. Do you have any remarks on that?

P1: I remember during COVID at a point where there was not a complete lockdown anymore but then they started to introduce this in Eindhoven at least in the library there where did study a lot. Umm you had to reserve timeframes as well because of COVID of course, and then you could see the number of seats that were eh, free, I think, or in use that's like kind of the same, ehm, that was back then quite useful, because you knew that they were quite specific: you had the entrance code and it got scanned by security guy. Ehm but of course people stayed longer than their time frame. So if you knew there were a lot of seats in use you probably knew like OK, if I'm late, then I might not even be able to find a space and then you get of course, really interesting situations where you start to uh, yeah what do you do then? That was interesting for now, yeah, I don't know, I've, I don't know about here the occupancy whether it's like what you said with the the window seats those are really limited and if they're really uh, appealing and the only reason that people might want to sit here, then it might be nice, but then yeah. Uhm, that's that could be nice.

P5: I'd say, I wouldn't check it every day, because usually it's not too busy and you could find a spot. But maybe in like exam weeks when you know the library is gonna be very full and it could be nice to see which spots are actually taking, because then you can see oh, it's only the deep depressing rooms or it's only the tables in the middle that are actually full. Like there are more people which can be distracting. Ehm, but yeah, I would say I would maybe check only when it's like actually busy the last two weeks of the module, maybe.

P3: I wouldn't really care about the predicted number of seats. Like I would just check it to see if there is something available and then go there.

R: Ok, yeah, just like in the moment when you decide to go.

P3: Yeah.

P6: Just the real time data, because..

P4: Yeah, normally when I also go in, I just check on the booking site like is there a room available right now and then normally I wanna book it for like 2 hours. So I then quickly set the times from well from now till 2 hours. Like "Is there any room available?" Normally there isn't. Eh, and then I just just go check if there's

anything available anyways. Eh, I don't really use the normal chairs like that much, but sometimes I I mean, if you just walk around, you can see like “Oh, there is a spot over there.” and you just go there. But yeah.

R: Also during exam weeks?

P4: Yeah.

P2: I think, like I wouldn't honestly care about any of these numbers, but that's also just a personal thing like I I prefer just to go there and see. I don't like checking data. Like for example you also have the same thing with train occupancy like where they show the expected people that are on the specific train. I don't really look at those things. I just see whatever and if I would end up in the library, you see that there's nobody there. I would just try to find a different place, but not plan in advance, whether it's the ambience or the amount of people suits me.

R: Yeah I see, OK, ehm, so I would like you to fill in something about this. Ehm, I have some visualization so this is very different than physicalization. Ehm but these are ways in which you could present data visually. This is normally how it's also done online, for example, to make it visible. Umm, what I would like you to do is just you already kind of mentioned what you would think about how valuable it would be to you, but I would like you to also rate it on a scale. So just fill this out. And if you have any ideas of something that would be either more valuable to you, there is also some space right down. Just take a few minutes to fill it in.

Session 2

R: OK, ehm, anyways, diving into this. So the focus group is really focused on ehm kind of analyzing the type of data ehm could that could be useful for you. Even if you're a frequent library user or not, it doesn't matter. Uhm, we're just gonna go through the questions. So my first question to you guys is how often do you visit the library for studying? Or do you even? Maybe someone wants to start answering?

P1: Everyday bro. No but uh very frequently I would say.

P2: About the next to go here,almost every day. Used to live here.

P3: For me, it kind of depends on the module, like if I'm really busy then yes I will be here quite often. If I don't have to study that much, then yeah, then I won't be here at all. So, it differs quite quite a lot.

P4: Ehm same for me, but I don't have any exams right now, but still I work here a couple of times a week.

P5: Yeah it also depends on how busy I am, but at least once a week I come here.

R: Okay good to hear, ehm, and what do you, so some of you come here everyday, but is this mostly just studying by yourself, or is it also project work for example?

P1: Ehm, I mostly come here to study by myself and mostly on the weekends I'm here. Usually during the day like to move to different buildings as well, just to kind of spice it up so it's not always the same building. But primarily to study there for exams or if I have to do some assignments or something, I come here and then use the big monitors.

R: Big monitors yes.

P1: At the library.

P2: Yeah. I used to switch. So I would go to Cubicus during the day and when it closes I come here and yeah, sometimes it stays open until 11 or during exams until 12. Uhm, so yeah, then I come here.

P3: I usually stu, eh study here for exams. Ehm, I think I have done in like the first few modules, maybe sometimes also for project. That we had a meeting, but like barely.

P4: Umm, I also come here for the big monitors. I don't have an extra screen screen at home. And at home I get very distracted so because then I can play music on my guitar and stuff like that and here I am just on my own working on my laptop.

P5: Hmm, yeah, I come here mainly to study by myself, but then ehh with with others in a project group. That's nice. And the monitors if they're free, but sometimes they're really busy, like the computer's not the other places.

P3: Yeah, I do also like to meet other people that are not in my project group just to sit together in a room so you can have a break together or something. But then I will still focus on my own thing.

R: Okay, so do you use the spaces, but not necessarily for group projects?

P3: Yeah.

R: Okay, I see.

P2: Yeah, I didn't use them for group projects either. I get very distracted by other people, especially if I know them. So, I'd rather be alone.

R: That makes sense, yeah.

P1: I mean at the library like one of the project rooms are empty on the weekends, I also use the project room by myself just because I don't know…

R: Why, why? Because it's like more closed off or?

P1: I I also like the big white board because I hate writing on paper, because then I just have just a lot of paper that I never use. And this way I can just like write, like if I solve exercises I just write them on the board and then delete them and don't have to like waste paper.

R: Oh that is interesting, so it's more facility based then? Cool! So, a bit more into like when do you make this decision? So sometimes, like, maybe it's also because it's convenient for you to go because you're already on campus. Like, when do you make this decision? Do you normally, are you normally at home and then you just decide to go here or are you already on campus and you're like "I'm just going to library"?

P1: I guess it depends. If I have to do a lot of like high focus work, I will probably go to the library. So if a lot of work I need to do a lot of things, I would go to the library. If it's a very small thing like I have to just like grammar check a report or something, I might do it from home because I don't wanna waste the trip here. But if it's like, I need to study for 5-6 hours, I'm like, OK, I'm gonna then do like deep focus study in the library because I like to keep my, as much as possible, like my study space and my living space separate. Because in my mind it's just easier to switch into one or other modes.

P2: Uh, so I used to live on campus. Uhm for a year, and then I moved to Hengelo. And, eh, of course it made it more difficult, but I was still here almost every day. So then I just would come to the library, do what I have to do, and especially during my thesis time I was here like every day because I prefer to work on the monitors and they don't have an extra monitor at home.

P3: Yeah, I usually study in the library if I just have a lot of work and I'm not already inside the building because of a lecture or something. Otherwise, I will just find a space in that building. Uhm, and yeah, if I'm home and then decide to go to the library, it's usually because, yeah, when I am just in my room, I get easily distracted and, and then I have a lot of work to do. So, that's not that useful.

P4: Uhm, yeah well for me, if it's a couple of hours then I'm going here. If I need to work uhm seriously but umm, if I don't have that, well, if I have more time then I eh sometimes also go to the SmartXP or a place where there's more distraction. Uhm, but I also like the idea of not doing it at home, because then you're at home and then it's your own place and then you're free and keep the studying part separately.

P5: Uhm, I live on campus, so it's easy to come here and I come here when I want to deep focus as well, also encourage me when other people are studying.

R: Since seeing people around you.

P5: Yeah.

R: Okay, yeah, so this is more ehm, I hear a lot of people, well, I hear a lot of you just decide from home already "OK, I'm gonna go to the library" or if you're at campus regardless, you also decide it. Uhm if you are in another building do you often look for a place there to sit, or do you deliberately choose to come here? Is there a difference for that or not necessarily?

P1: Hmm, I guess it depends on the building. For example, I really like, is it called Langezijds. That one I really like studying there, so if there's space, I would, and if I'm let's say in Ravelijn had a, like sure I would go there first because it's closer. But for example, if I know that I it's already like 6 and I need to stay for three or four hours, I will go immediately to the library because otherwise I have to move in the middle of studying and it just breaks my focus. So, it then depends as well.

P3: Yeah for me it's a bit the same as P1.

P4: Yeah, same for me.

P2: For me, yeah, I had specific places I would sit in the different buildings, but I prefer like Cubicus or sometimes TechnoLab. Uhm, but yeah, I think, I would say like Cubicus would be my number one and the library 2nd and then TechnoLab, but I will still be here more often because it stays open until late.

R: Exactly, it's more accessible than other buildings. I see. Uhm, yeah, I think this is already kind of answered. It kind of depends on also accessibility. So if the building closes, I think that's most of the time.

P5: Yeah, also here it's mostly silence, so it's good to focus.

R: Yeah, it is different from other buildings in that sense, yeah, OK. So then, uhm yeah, specifically regarding the data. So, there is data in theory possible to get. Umm would this influence your decision? That's basically what I'm trying to find out because there are like a number of things that could be shown either in real time or also predicted, for example. Would you, like imagine, would you think that you would think this information is useful to you and at one moment would that be useful?

P1: I would definitely think it's useful, especially if I am deciding because for example, some days during the week I "Maybe I wanna go to the library or some other building" and then depending on how busy it is, I might go to a different building. So I think the number of visitors that are currently like in the library is also helpful because if there's too many then it's just too distracting and you feel like you are not cubicle and it's just not my like, so yeah, I would say it's useful when deciding if I wanna go to the building or not. I like it when it's a bit more empty so yeah.

P3: Yeah, but also to like see if there are actually places you can sit at.

P2: Yeah, and also I know during exam weeks it's like very packed in here and then I have to go all over to look for a place to sit and then I don't find a place to sit and then I have to go sit in another building or something. So, it's useful then to know.

R: Yeah, if it's literally packed and there is no place.

P4: And also the facilities, the extra screen, sometimes they are also, yeah, there are no free screens anymore. So then I also have to go somewhere else.

R: Yeah, so then the reason that you came was necessarily for the screen. So if you don't find it, yeah, okay.

P5: I think the area because they have like different areas for the library. So if you want to be just in a cubicle, then it would be nice to see if there are any free instead of just walking around all of them.

R: Yeah, OK, nice! I have eh a small form that would like you to fill in. It's kind of like like a likert scale. So it's just all of the information and I also have a visual for all of them. These are visuals that could be created with them just to help you maybe imagine how it could be presented visually. I would like you to rate it just in terms

of usefulness to you. Uhm, and you can just also take into account how it could be visualized. But these are all kind of possible for each type of data, so base your answer more on the type or nature of the data.

Session 3

R: I'm just gonna, uh, show a few questions and I just want to get you get your insights on it. So, first question, ehm, how often do you visit the, do you ever visit the library? Ehh, and for what? Maybe we can go around? Maybe you can start?

P1: Uh, I very rarely visit the library. And for studying it's only in group projects when maybe someone else in the group has to plan it and then chooses the library.

R: OK.

P1: So that is maybe one time per two months or something.

P2: Eh, I also use the library very barely. Uhm, yeah, I'm also mostly with other people. If I can plan it myself, I'm usually not in the library either. So maybe, yeah, also once every two months.

P3: Uhm I think I did it a lot during my bachelor, so both like on my own and in groups, but since my master, I don't think I really came to the library anymore.

R: OK.

P4: I do it every week. But that, uh, because of my honours group, we decided to meet altogether on every Saturday in the library.

R: Ah I see, OK. So, that was also a group decision?

P4: Hmhm.

R: OK, I see.

P5: I also don't go to the library that often. Usually because of other people. So I would say maybe two or three times a month I'm in the library.

P6: I used to go the first semester of my first year, but now I don't go at all. Never yeah.

P7: I go about once a month when I'm feeling that I'm not being productive at home and then I get myself to go somewhere and where everyone is studying and then I come here. But it's only in those occasions.

R: I see. So, uhm, are there any other study areas around campus that you often go to like a very specific one or?

P1: Yeah. The Cubicus. Uh, quite almost every day now, I think. Yeah, Cubicus or theater cafe as well. So that is in this building.

R: And what is the reason where you, why you go there instead of somewhere else? Is it because it's close to your classes or eh?

P1: Cubicus, I don't actually have class in Cubicus, but it's because Idefix is there and P2 is there and P6 is there. Ehm and then for theater cafe, it's usually connected to like getting lunch or getting a drink, something that.

P2: Yeah, for me, the same, Cubicus, almost every day. Also, because the study association is there so you can just grab tea and coffee and everything. Ehm. Yeah. Sometimes in Carre also, but mostly in between classes then if I have class there. And also in theater cafe. Yeah, if I wanna get a drink and that's maybe once a week probably.

R: I see, what about you?

P3: I think the Honours room. Honours office. Ehm, and during my thesis the interaction lab because then the equipment was there, so that made sense.

R: Yeah, that makes sense.

P4: For me Technohal. I don't actually have any lectures and Technohal, but I just like the feeling, I, I think it's my favorite building.

R: So it's really building related more?

P4: Hmhm.

R: OK.

P5: DesignLab, because it's design lab. I, I don't like silence as much as I like like background noise. So that's nice.

P6: Uh Cubicus as well. For the Idefix room so you get coffee and stuff and the social element. And sometimes I'm in the sports canteen, but that's very rare.

R: How about you?

P7: For group projects and meetings, uhm, yeah, usually not really my own DesignLab as well. For studying on my own, I usually just, I'm, I'm at home, so nowhere on campus.

R: OK. OK, so the rest of the questions are really related to people that more often visit the library. So I'll just show them, uhm, but it's more related to how is your decision making decision making process in deciding when to go and also what would be reasons that you might not go. Umm is there any specific like I hear from most of you that there's just a habit of either going to specific building. Is there any other factor that is integrated in it? So for you, for example, it's you like the crowdedness, you like the building I assume, but is it also its social elements? Is there something else?

P6: For me, I used to go to the quiet section of the library, but it's just not respected. People are very frequently talking, walking into it. They're opening the doors to quiet rooms, and so it's like, well, if I'm gonna go somewhere noisy, I'd rather have somewhere that's it expected. And there's all the other elements that I mentioned.

R: I see. OK. Anything else?

P1: Yeah, it's also the social element is important, I think. And I usually have like meetings during the day sometimes. So then it's nice at I'll have the, so if if you're in a quiet spot you cannot take the meeting there, but you're also not sure if there's a project room or something, then yeah.

R: Yeah, so also availability in that sense, eh, is important.

P1: Yeah.

R: OK.

P2: Yeah, I think also that it's central on campus. So, when you're at Cubicus you can very easily move between buildings, if you have things in between. Whereas I feel like if you're in the Horst, for example, yeah, that's less.

R: Yeah, yeah it's more central. OK.

P3: Maybe the number of distractions. So, I think when I still used the Citadel, so the Interaction Lab, I would go there if I sort of wanted to be left alone and just work on my thesis project. Then I would sit and what I do

now is sit in the Honours room if I sort of allow myself to be found by people who like need to have me for something.

R: Yeah.

P3: But then it's nice to get like an escape where I'm like, oh, I'm not there, but I'm actually working in quiet.

R: Yeah, that makes sense.

P3: So maybe I should go to the library more often. I have been thinking about it.

R: OK. Nice. Ehm, I don't know if anyone else would like to share? So, ehm, so the project I'm doing is more related to occupancy data, so it's often for people that more frequently use, for example the library or any other building. Is availability of seats ever problem in the buildings that you attend? Because like if you have DesignLab for example, it might be really crowded. Is that also maybe then a reason why you leave building and go somewhere else to find a spot? Or does it ever happen in other buildings?

P1: For Cubicus, because we are usually quite early, there's always a spot, but I, I know today. Eh so they have like some, because we are usually with more people, you need a big table and if the big table is not available we can always go to the association room as well. So then, there's always never really eh like I prefer to see sit at like the, like the you have a low area in the Cubicus that is the best, but you can always sit somewhere else.

R: OK.

P3: Maybe eh, it's kind of funny when the Technohal was just opened and everyone started sort of crowding there, you could never find a table there. And now that Langezijds is open I wanted to sit there, you know, with the the nice plants and everything and I thought, oh, that's cute, but then there's never space there. So now I moved to another building. So, they need more, a new building again, so I can sit in Langezijds.

R: I see.

P4: And I think it also just depends on like if it's exam season or not. Like I think also the library, eh, like it's usually just full or the project rooms and then like there has been multiple times where we had to sit like, ehm, outside at the cafe there near the theatre. Yeah.

R: In the theater café?

P4: Hmhm.

R: I see.

P5: DesignLab it can be crowded, but there's always at least one spot somewhere, because it's usually also the main areas are like crowded, but people don't know about LearnX and Inspire and Inform. So I never, I almost never struggle with finding a room unless there's an event or something. Much more commonly would walk into the library and not find a space and then like sit in the somewhere else in the Vrijhof.

R: I see. OK. Yeah, because there is of course library information that could be shown to people that might be interested in seeing this information. So I have some examples. Ehm, imagine, maybe in another building as well, but what type of data would be interesting? Because for example, there's a difference between a predicted number or for example the history throughout the day. Ehm, for some people, that might plan ahead, this might be interesting, but ehm yeah, is there any of the examples that would stick out to you or would be useful to know at any certain moment?

P6: I think the second one, ehm, just because I think Google Maps has a feature similar to this where when you search location it can tell you what the time you're looking, typically busy or typically not busy stuff. So, I think I would be more interested in that than maybe the exact number of seats because I, I don't know how you'd even work that out. Yeah.

P7: I think for me that the number of free seats would be useful to see if, yeah, in those really crowded moments, which in my case I only go to the library when I have a deadline and I'm not concentrated at home, which is usually aligning with exam periods, which is also the busiest time. So already knowing in advance that there is at least one free seat for me somewhere in the library that would be useful information. To not just go and waste time.

P8: I don't know about like free seats, because if like, it takes me a bit of time to get to the library like a bit knowing there's exactly 5 seats left doesn't mean much because it's probably gonna change for the time that I get there. But like a general, I don't need that that much detail, but if I can see the past how full it was and then the now so like a general how much people are in the library graph, then I can compare it to "Oh, I was there on Tuesday, and it seemed like there was a lot of spaces left, and now it's the same as Tuesday" so there's like a just a general overview of how many people are in the library at what times.

P1: I would also be interested in seeing how many projects spaces are free. I know the resource Booker I think theoretically theoretically should be able to do that, but it is so unusable I think that it's it would be nice that you can just see it more clearly at the time that you're looking.

P3: I think I mean, I would also like in the the the trend of how busy it is because that's sort of I think for me it's more about distractions. You know if if you would also know how loud it is, it's probably not really in your thesis. But if I would know like how sort of like what the noise is if if it's like more than usual, then I think I probably will not go even if there are plenty of seats. But that's, I don't know, this maybe a very different metric, but I, I think it would be more like I'm fine with there being a lot of people just as long as they don't distract me I guess.

R: I see, yeah, in theory actually about that, they are. Uhm, the library is collaborating with the Digital Society Institute. And they're actually looking into more sensors place. So there might be at some point that they might analyze the noise, for example, and also in the project rooms they actually have heat sensors because of energy regulations and they are trying to also maybe use that data. But that's the thing like they have to sensors, but they now are only using it for certain specific goal and they don't know if this would be interesting. So unless it is, they won't actually do anything else with it. But uhm yeah, all good suggestions that would say umm, I have a bit of a form so you can rate uhm the and the types of data based on their usefulness. And I also have some graphical representation, so I think some like I think you also mentioned the number one that's kind of how Google also does it I think. It's kind of like historical. Of course, these visuals can all ready, can all kind of be interchanged sort of. But just to give you an idea of how it could be presented visually. Ehm, yeah, please just rate them I have some pens in the rating forms and underneath there's also an open question if there is any suggestions you have of other types of data that might be useful to you.

Appendix F Information letter and consent form participatory design workshop

These documents present the information letter and consent form provided to the participants before the start of the participatory design workshop.

Design Workshop Information letter

Study: Physicalization of real-time library occupancy data

Purpose of the Research Project

The purpose of this research project is to design, create, and evaluate a real-time data physicalization that displays occupancy data of the University of Twente Library.

Goal of the Participatory Design Workshop

The Participatory Design Workshop is used in this phase of the study to gather essential information from students, which will be invaluable for creating an effective data physicalization. Your input will be used to determine the requirements, opportunities, and possible dimensions of the physicalization.

Design Workshop Details

The design workshop will be held at the Vrijhof at the University of Twente. You will join a group of approximately 6 fellow students. The workshop will be video recorded. During the introduction of the session the researchers confirm that you have given consent for this. Below is given an overview of the entire session:

1. **Welcome and Introduction (10 minutes):** The researchers welcome everyone and provide an overview walkthrough of the study and the workshop session.
2. **Focus Group Activity (20 minutes):** The group is asked to engage in a discussion about occupancy data to explore valuable insights. The researchers will ask questions like, "How often do you use the library for your study or work?" and "If you had access to real-time occupancy data, what specific information would be most valuable to you as a student?"
3. **Designing Data Physicalizations (30 minutes):** In the next part, you will be part of a smaller group (3-4 students) to create designs for data physicalizations of library occupancy data. You will be asked to design a physicalization for a specific dimension: private (such as in the home environment) or semi-public (at the university). The researchers will provide materials such as modeling clay, paper, pencils, cardboard, and various everyday objects. After the round of designing, the researchers gather the designs and there will be a group discussion about them to gather additional feedback on their aspects.

The entire workshop will take approximately 1 hour.

During the workshop, you should be safe from any sort of risk. The workshop setup of this study has been reviewed and approved by the Ethics Committee Information and Computer Science.

You are allowed to withdraw from the study at any time. There is no penalty for not participating or for withdrawing from the study. If you want to withdraw from the study, you can notify one of the researchers. Any information about you gathered in the workshop will then be deleted.

Data collection

Some personal data will be collected for research purposes. Your responses will be anonymized and aggregated for analysis purposes; this includes any screenshots from the video material that may be utilized in the project report. As the data will be anonymized after collection, there is only a short time frame in which you have the option to request access to and rectify or erase this data after the workshop has concluded.

All your responses and information will be kept confidential within reasonable limits. We will minimize any risks by storing all the collected data on secure servers that are only accessible by authorized personnel involved in the research. We will retain the data for a period of six months, after which it will be securely deleted. The privacy and confidentiality of your personal information are of utmost importance to us. We assure you that all data collected in this survey will be treated with strict confidentiality and stored securely. No personally identifiable information will be stored or disclosed in any reports or publications resulting from this workshop.

Contact

For any further questions please ask them to one of the researchers or send an email to s.m.fuentesbongenaar@student.utwente.nl. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researchers, please contact the Secretary of the Ethics Committee Information & Computer Science: ethicscommittee-CIS@utwente.nl.

Consent Form for Seamless Integration of Real-Time Campus Occupancy Data

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 23/11/2023, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves an audio-recorded interview and a video-recorded workshop session, where these recordings will be transcribed as text and the recordings will be destroyed after the research has been conducted.	○	○
Risks associated with participating in the study		
I understand that there are no risks involved in participating in this study.	○	○
Use of the information in the study		
I understand that information I provide will be used for a bachelor research paper.	○	○
I understand that personal information collected about me that can identify me, such as [e.g. my email address], will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs.	○	○
Consent to be Audio/video recorded		
I agree to be audio and video recorded.	○	○
Future use and reuse of the information by others		
I give permission for the anonymised transcripts of the audio and video recording that I provide to be archived in a private database so it can be used for future research and learning.	○	○
I give permission for the pictures of the designs that I create during the workshop to be archived in a private database so it can be used for future research and learning.	○	○

Signatures

_____	_____	_____
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Susanne Fuentes Bongenaar		_____
Researcher name	Signature	Date

UNIVERSITY OF TWENTE.

Study contact details for further information:

Susanne Fuentes Bongenaar - s.m.fuentesbongenaar@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

Appendix G Tagged physicalization design descriptions

Idea 1: Colour-changing keychain

One group presented a number of ideas for utilising a keychain for showing library occupancy data. This first idea was inspired by a lava lamp, featuring a vertical, circular design with electronic components encased at both ends. In the centre there is a transparent unit filled with a liquid chemical capable of changing colours. The chemical composition in the centre is altered to emit different colours of light, corresponding to the number of people in the building. For instance, a green light could indicate low occupancy, yellow light a moderate level, and red light a high level of occupancy. As users are able to carry and quickly access the device, it provides an immediate visual cue of the library's current occupancy state.

Idea 2: Vibration keychain

Another keychain that was proposed utilises vibrations as a medium to convey occupancy data. The keychain is designed with a button that can be pressed to let the portable device vibrate to signify the library's occupancy level. The intensity and duration of the vibration correlate with the number of people present in the library. For example, gentle, short vibrations would indicate low occupancy and intense, long vibrations for high occupancy levels. Additionally, buttons could be added to the keychain to give users the ability to select different areas within the library or other buildings. Alternatively, the single button could be used to select specific areas with different press sequences, although this would require users to memorize the sequences.

Idea 3: Thermal keychain

A third keychain that was presented translates the library's occupancy level into thermal feedback. The keychain changes temperature based on the number of people present in the library. The device would be cool to the touch in low occupancy situations and would gradually increase its temperature as the space becomes more crowded. When the library is completely occupied, the keychain would be at its warmest.

Idea 4: Sound keychain

The following keychain idea was proposed by the participants based on soundboard technology. The keychain features a small board equipped with multiple buttons, each representing a different area within the library. By pressing a button, the user is able to trigger a sound that reflects the occupancy in the selected area. The occupancy level could be translated through the sound level or with the type of sound. For example, a soft sound could indicate few people, while a louder sound corresponds to a higher occupancy. Alternatively or additionally, the type of sound could represent the occupancy level. Where for example a calm nature sound could present low occupancy and the sound from a thunderstorm could indicate high occupancy levels.

Idea 5: Light keychain

The last keychain idea that was proposed utilises the concept of a traffic light for its design. The device features a number of LEDs in a vertical line, much like a traffic light, with a colour spectrum ranging from red to green. A button is integrated into the keychain that upon being pressed lights up one of the LEDs. The library's occupancy data would be translated into this spectrum range of colours. For example, red would represent more people in the library and green indicates a less crowded situation. Additionally, if the button is pressed multiple times or in a certain pattern, other information, such as the occupancy in specific areas, could also be presented.

Idea 6: Library map card

Another portable idea that was proposed came from the concept of a card, such as a bank or transportation card. The card would show a small map of the library and the levels of occupancy would be indicated through certain areas that would light up. For example, study areas or places that are free

could be lit up on the map, whereas occupied places would stay dark. Alternatively, the card could show exactly the opposite, where there are more people, there is more light shown. The colour of the light could allow for showing both the free spaces and the most crowded areas. In this case, the areas on the map could have a red colour indicating high occupancy, whereas a green colour could show low occupancy. This could be integrated into the student card of the university where the library is located.

Idea 7: AR Smartwatch

An idea that was proposed utilized the technology of smart-watches and augmented reality (AR). In this concept, if a user wears some device on their wrist, like a smart watch, it can project a 3D digital twin display of the library above the device's surface using AR technology. To view this digital twin, the user would need to wear either a headset or AR glasses. The digital twin provides visual cues through colour indications, enabling the user to see the varying occupancy levels throughout the library.

Idea 8: Responsive jacket

Another idea that was proposed involved a specialized jacket that can be worn by students. This jacket has the ability to contract when the occupancy in the library increases, providing a direct pressure on the upper body of the user. Conversely, when the occupancy is lower, the jacket expands and relaxes, losing its grip on the body. This approach simulates the sensation of crowdedness in an environment, letting the user physically feel the changes in occupancy.

Idea 9: Elevating library map

A number of ideas that were proposed during the design workshop included objects that can be placed on a desk or on a flat service. Among them is a desk-sized object that was proposed that includes a 3D map of the library. The occupancy level of the different library sections is represented through the varying elevation of these sections within the object. Each area rises in height proportional to the number of people present in that space. The scale of elevation is relative, with the lowest point indicating an empty area and the highest elevation showing maximum occupancy.

Idea 10: Miniature building

A second desk-sized concept that was presented, involved a miniature version of the library building. By pressing a button, users can activate the miniature object and observe certain areas being lit up within the small building. The lights serve as indicators of occupancy of specific areas in the library. For example, areas with many seats available, may be highlighted with brighter or lighter tones. On the contrary, areas with high occupancy levels are shown using dimmer or darker tones. Additionally, the design allows for the incorporation of LEDs that specifically indicate seats, showing that they are free or occupied through the use of light.

Idea 11: Responsive sculpture

Another idea of a desk-sized object dynamically translates library occupancy data through physical expansion and contraction in art sculpture. This sculpture is able to grow or inflate when the library is highly occupied and can decrease in size or deflate when occupancy is low. Materials such as sponges that absorb water, or objects that expand with air, such as balloons could be utilized to create this sculpture. The sculpture could be placed at home on a desk as decoration, but also be put at the entrance of buildings.

Idea 12: Responsive plant

Building upon the idea of items that can be placed around the house, this concept utilizes the growing character of plants to demonstrate library occupancy levels. The (conceptual) plant grows taller or extends its form to reflect a high occupancy level in the library, while it contracts or diminishes in size when the library is less occupied. Instead of using natural plant materials, the design could be a plant-like structure with integrated LEDs and other materials. In this way, the growing effect of plants can be done by lighting up more LEDs and diminish in size by switching them off. This plant could be placed

at home or at the entrance of the building, where users can grasp the crowdedness of the library through observing the plant.

Idea 13: Adaptive painting

An artistic idea that was proposed by one of the groups translates occupancy data in a painting. This digital painting can change its style according to the level of occupancy in the library. For instance, a quiet scene showing still water with a lone boat may represent a low occupancy level. In contrast, a high occupancy level may be illustrated through a vibrant cityscape, with illuminated windows and crowded streets. While this digital painting can serve as an indicator of the crowdedness in the library for university students, it is simultaneously a visually appealing and aesthetically pleasing artwork that can add an artistic element to the environment.

Idea 14: Ambient music

An idea that moves away from visual and tactile cues, was introduced by a group suggesting the translation of library occupancy data into music. In this idea, the music's volume intensifies as the library becomes more crowded and the style of the music changes to reflect a busier ambiance. Contrastingly, when the occupancy decreases the volume of the music lowers, and its composition becomes simpler, having fewer instruments playing at the same time or less complex arrangements. This presentation of library occupancy data could be played in various settings, such as at home, at the entrance of a building, or even on personal devices like phones or laptops.

Idea 15: Overhead light indicator

Diverging from the ideas focused on library occupancy data, this concept involves converting noise data into visual cues using light. In this system, the sound level in each area or at each seat within the library is monitored. When the noise in a specific location exceeds a predefined threshold, lights positioned above this area would light up in a distinct colour, such as red. This serves as a signal to library users, making them aware of their noise levels and encourages them to behave more quietly. Additionally, this light system can also function to indicate the availability of seats. For example, a green light can indicate a green space, if there is no light it means that the place is occupied, and when the light is red it means that the user is too loud.

Idea 16: Candle display

One group presented an idea to display project room occupancy data using a desk-sized object. This object features a display with small (electric) candles, one for each of the project rooms. The real-time occupancy data of these rooms is conveyed through the candle's light. A lit candle indicates that the room is occupied, while an unlit candle means that it is available to use. The design mirrors the concept of warmth generated in a project room when it is in use, with the lit candle service as a metaphor for the presence of people and activity within the space.

Idea 17: Library fountain

Another physicalization idea that can be placed at the entrance of a building, features a small fountain. This concept translates the number of people present in the building into the water flow of the fountain. Specifically, the fountain increases the amount of water it propels upwards in direct correlation with the increasing number of library occupants. As a result, when users pass by the fountain, they can grasp the level of occupancy of the building by observing the height and volume of the water.

Idea 18: LED map

The following idea involves a map that can be mounted to the wall and translates library occupancy using light. This map includes a layout of the library with each seat or space represented by a LED light. While passing by, users can easily observe it to understand the current occupancy in the library: the colour of the LEDs signify the occupancy status of each spot. For instance, green lights indicate free seats, red lights show occupied study spaces, and yellow lights indicate seats that are currently free but reserved and will be soon occupied. Additionally, the map can display the exact number of free seats

and project rooms, either as text or through progress bars. This feature offers users a direct understanding of the library's crowdedness, as opposed to a more dispersed and less immediate interpretation provided by the individual lights.

Idea 19: Footprint projection

Another idea that is intended to be displayed at the entrance of a building, uses visual projections on the floor to represent the occupancy of the library. Upon entering the building, the footprints of a visitor are projected onto the entrance floor. These footprints remain visible as long as the individual is inside the building and disappear once they exit. The density of these projected footprints on the floor directly correlates with the real-time number of people in the library. This method provides students with an immediate and intuitive visual cue of the current occupancy level.

Idea 20: Magnetic art piece

A more artistic concept was introduced by one group that involves an art installation with metal balls and adjustable magnets. This piece operates by rearranging magnets to form a specific number on the wall. When activated, metal balls are released from above the installation, with some balls remaining suspended in mid-air, held by the magnetized numbers. This creates a visual display of a number, representing the current occupancy of the library. In this way, passersby can easily observe and interpret this number formed by the metal balls. After a set period, the installation resets itself. The art piece can be activated either by users pressing a designated button or automatically through motion sensors detecting movement near the installation.

Idea 21: Interactive animatronic

An idea that was proposed features an interactive animatronic as a means to communicate library occupancy data to passersby. Placed at the entrance of the building, this animatronic is designed to speak and respond to users through speech. It can be activated by detecting movement or can be prompted through auditory cues, such as spoken words from users, or by pressing a button. The animatronic is provided real-time data on the occupancy of the library and can provide specific information about different areas within the library. Additionally, a network of these animatronics could be placed across the university campus in multiple buildings. This network would enable the animatronic to share occupancy information from multiple locations, offering an interactive and informative experience for students moving throughout the campus.

Idea 22: Fibre optic flower

This idea involves the integration of a fibre optic cable system within the library building. Central to this concept is a fibre optic 'flower' that is located at the entrance of the library building. From this flower, cables extend across the ceiling to various study areas and places within the library. The illumination of a fibre optic cable signifies that the corresponding space is available for use. Moreover, the colour of the cable indicates the type of space: green for individual seats, orange for table seats, and pink for project rooms. At the entrance, students can quickly assess the overall availability of spaces by observing the flower, where all the fibre optic cables come together. Afterwards, students can easily find and follow the specific coloured cable on the ceiling to reach the specific type of study space. Additionally, every building with study spaces could feature a similar central display, surrounded by smaller flowers that indicate the real-time occupancy of other buildings on campus. This system provided a visual and intuitive method for students to navigate and find available study areas within the library and across the campus.

Idea 23: Miniature Campus Map

A desk-sized object idea that was proposed includes a detailed miniature 3D map of the entire campus that can be displayed in each building entrance. This map showcases every campus building as a distinct, movable element, with its height varying to indicate occupancy levels. Specifically, a lower position represents minimal occupancy, while a higher position indicates greater occupancy. Uniquely, each building would have a 3D map designed to reflect the character of its respective department. For

example, in the Engineering faculty building, the map elements could resemble components on a circuit board, with each representing a different building. Similarly, for the Medical faculty, the elements could be styled to reflect health and medicine themes. Users can easily view this map to understand the occupancy levels across multiple campus buildings at once.

Idea 24: Birdsong system

The following idea uses sound to convey the occupancy data of the library. In this idea, speakers are installed in the boulevard, which is the outside area next to the library building. These speakers will play distinct bird songs, each correlating with different occupancy rates within the library. Over time, this setup aims to foster a subconscious association among users, linking the type of bird song to the availability of space in the library. This concept offers an unobtrusive method of translating occupancy data, easily integrated into the outdoor environment of the library. Users can interpret the crowdedness of the library simply by listening to the bird songs as they pass by or spend time in the boulevard area.

Idea 25: Inflatable dolls

Another concept that was ideated upon with the idea to be placed in the boulevard area features an arrangement of inflatable car wash-style dolls, each representing a different building on campus. These dolls are designed to inflate or deflate in response to the occupancy levels of their corresponding buildings. For a building with low occupancy, its respective doll will be fully inflated, visually inviting students to visit this less crowded space. Contrastingly, a building with high occupancy will have its doll less inflated, demonstrating the crowdedness in the building. This physicalization offers a dynamic and easily interpretable visual for students to assess the occupancy of various campus buildings at a glance.

Idea 26: Coffee taste

A concept that was proposed utilises gustatory feedback as a means to communicate the occupancy levels of the university library. It involves altering the taste of coffee dispensed from the machines within the university library. The system adjusts the bitterness of the coffee based on real-time occupancy data. As the library reaches higher occupancy levels, the coffee dispensed from the machines incrementally increases in bitterness. The shift is intended as a nudge for visitors to consider moving towards less crowded spaces on campus. Conversely, during periods of lower occupancy, the coffee remains less bitter. This application provides library visitors with an implicit signal about the current level of occupancy through the taste of their coffee.